USAID
FROM THE AMERICAN PEOPLE

# USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin

November 2013

# Main Report

## USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin

# Main Report


This publication has been made possible by the support of the American People through the United States Agency for International Development (USAID). The contents of this document are the sole responsibility of International Centre for Environmental Management (ICEM) and Development Alternatives Inc. (DAI) and do not necessarily reflect the views of USAID or the United States Government.

| | |
|---|---|
| Project Title: | USAID Mekong Adaptation and Resilience to Climate Change (USAID Mekong ARCC) |
| Sponsoring USAID Office: | USAID/Asia Regional Environment Office |
| Contract Number: | AID-486-C-11-00004 |
| Contractor: | DAI |
| Date of Publication: | November 2013 |
| Cover Photos: | Saowalak J. / Dan Rathbun |


Published in Bangkok, Thailand
March 2014; USAID Mekong ARCC Project (http://www.mekongarcc.net)

# USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin

**Citation:** ICEM. 2013. USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin: Main Report. Prepared for the United States Agency for International Development by ICEM – International Centre for Environmental Management. Bangkok: USAID Mekong ARCC Project. Available online at: www.mekongarcc.net/resource.

**Study team:** Jeremy Carew-Reid (Team Leader), Tarek Ketelsen (Modeling Theme Leader), Jorma Koponen, Mai Ky Vinh, Simon Tilleard, Toan To Quang, Olivier Joffre (Agriculture Theme Leader), Dang Kieu Nhan, Bun Chantrea, Rick Gregory (Fisheries Theme Leader), Meng Monyrak, Narong Veeravaitaya, Truong Hoanh Minh, Peter-John Meynell (Natural Systems Theme Leader), Sansanee Choowaew, Nguyen Huu Thien, Thomas Weaver (Livestock Theme Leader), John Sawdon (Socio-economics Theme Leader), Try Thuon, Sengmanichanh Somchanmavong and Paul Wyrwoll

The USAID Mekong ARCC project is a five-year project (2011–2016) funded by the USAID Regional Development Mission for Asia (RDMA) in Bangkok. The larger project focuses on identifying the environmental, economic, and social effects of climate change in the Lower Mekong Basin (LMB), and on assisting highly exposed and vulnerable rural populations in ecologically sensitive areas adapt to climate change impacts on agriculture, fisheries, livestock, ecosystems, and livelihood options.

This phase of the project was led and implemented by ICEM, and focuses specifically on predicting the response of the key livelihood sectors—agriculture, livestock, fisheries, rural infrastructure and health, and natural systems—to the impacts associated with climate change, and offering broad-ranging adaptation strategies to the predicted responses.

This volume is part of the USAID Mekong ARCC study set of reports:

1. USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin: Summary
2. USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin: Main Report
3. USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin on Agriculture
4. USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin on Livestock
5. USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin on Fisheries
6. USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin on Non Timber Forest Products and Crop Wild Relatives
7. USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin on Protected Areas
8. USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin: Socio-economic Assessment

Documents Six through Eight are works in progress.They were prepared as resources and sources of data that will continue to be updated as new information comes to hand and analysis is undertaken by the project partners.

# ACKNOWLEDGEMENTS

The study team wishes to give a special thanks to Brad Phillips, USAID/RDMA's former Climate Change Adaptation Advisor, for his vision in recognizing the need for this study and for providing excellent technical guidance and suggestions throughout.

The team also specially recognizes the strong support of the USAID Mekong ARCC team who provided regular technical inputs as well as continuing management and communications support: Paul Hartman (Chief of Party), Christy Owen (former Deputy Chief of Party), Sumalee Santadkornkarn (Senior Administrator), Saowalak Jingjungvisut (Communications Specialist), and Shelley Gustafson (Scientific Editor).

Two regional workshops were undertaken as part of the study and the team would like to thank the close to 200 participants for extensive contributions.  They included technical representatives from the four LMB governments and many national and international organizations and individuals working in the fields of climate change, agriculture, livestock, fisheries, natural systems, and socio-economics.

Special thanks to the Mekong River Commission Secretariat for a number of technical round table discussions and consultations and provision of important data and advice, especially staff of the Environment Program and Climate Change Adaptation Initiative.

And finally, the team extends its thanks to the formal technical reviewers who attended team working sessions or provided detailed reviews of the draft Main Report and individual theme reports including: Rod LeFroy (International Centre for Tropical Agriculture – CIAT), Caitlin Corner-Dolloff (CIAT – Vietnam), Colin Khoury (CIAT), Steve Staal (International Livestock Research Institute – ILRI), Fred Unger (ILRI), Okeyo Mwai (ILRI), Jo Cadilhon (ILRI), Derek Bacher (ILRI), Delia Grace (ILRI), Joachim Otte (Food and Agriculture Organization Regional Office for Asia and the Pacific), Robert Mather (International Union for the Conservation of Nature), Benjamin Samson (International Rice Research Institute – IRRI), Reiner Wassmann (IRRI),  Kasina Limsamarnphun (Oxfam), Simon Funge-Smith (Food and Agriculture Organization), Caspar Ammann (National Centre for Atmospheric Research – NCAR), Apanie Wood (ICEM) and Beau Damen (FAO).

# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| 3S River Basins | Sekong, Sesan and Srepok River Basins |
| ACIAR | Australian Centre for International Agricultural Research |
| AEZ | Agro-ecological Zone |
| AGAL | FAO Livestock Information, Sector Analysis and Policy Branch |
| AH | Animal health |
| AI | Artificial insemination |
| ASEAN | Association of Southeast Asian Nations |
| AusAID | Australian Agency for International Development |
| CAM | Climate Change Adaptation and Mitigation Methodology |
| CBD | Convention on Biological Diversity |
| CC | Climate Change |
| CGIAR | Consultative Group on International Agricultural Research |
| CI | Conservation International |
| CIAT | International Center for Tropical Agriculture |
| CSF | Classical Swine Fever |
| CWRs | Crop Wild Relatives |
| ENSO | El Nino / Southern Oscillation |
| EVI | Extreme Value Index |
| FAO | Food and Agriculture Organization of the United Nations |
| FAOSTAT | Statistics Division of the FAO |
| FMD | Foot and Mouth Disease |
| g/L | Grams per liter |
| GAP | Good Agricultural Practices |
| GCMs | General Circulation Models |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gas |
| GIZ | Gesellschaft für Internationale Zusammenarbeit |
| GLiPHA | FAO Global Livestock Production and Health Atlas |
| GMS | Greater Mekong Subregion |
| GSO | General Statistics Office of the Government of Vietnam |
| ha | Hectare |
| HS | Hemorrhagic Septicemia |
| ICEM | International Centre for Environmental Management |
| ICT | Information and Communications Technology |
| IEA | International Energy Agency |
| ILRI | International Livestock Research Institute |
| IPCC | Intergovernmental Panel on Climate Change |
| IPCC AR4 | IPCC Assessment Report Four |
| IRRI | International Rice Research Institute |
| IUCN | International Union for Conservation of Nature |
| IWRM | Integrated Water Resources Management |
| km | Kilometer |
| Lao PDR | Lao People's Democratic Republic |
| LIRE | Lao Institute for Renewable Energy |
| LMB | Lower Mekong Basin |
| LU | Standardized Livestock Units |
| LUSET | Land Use Suitability Evaluation Tool |

| | |
|---|---|
| $m^3/s$ | Cubic Meter per Second |
| MAFF | Ministry of Agriculture, Forestry and Fisheries, Cambodia |
| masl | Meters Above Sea Level |
| MCM | Million Cubic Meters |
| MDGs | Millennium Development Goals |
| Mekong ARCC | USAID Mekong Adaptation and Resilience to Climate Change Project |
| mm | Millimeter |
| MPI | Ministry of Planning and Investment, Lao PDR |
| MRC | Mekong River Commission |
| MT/yr | Million Tonnes per year |
| NAFRI | National Agriculture and Forestry Research Institute, Lao PDR |
| NCAR | National Centre for Atmospheric Research |
| NTFPs | Non-Timber Forest Products |
| OVS | Overall Suitability Value |
| PAs | Protected Areas |
| PET | Potential Evapotranspiration |
| PRRS | Porcine Reproductive and Respiratory Syndrome |
| RCG | Royal Government of Cambodia |
| RCPs | Representative Concentration Pathways |
| SIWRP | Southern Institute for Water Resources Planning |
| SLR | Sea Level Rise |
| SPS | Sanitary and Phytosanitary measures of the WTO |
| sq km / $km^2$ | Square Kilometer |
| SRES | Special Report on Emissions Scenarios |
| SRI | System of Rice Intensification |
| TNC | The Nature Conservancy |
| UMB | Upper Mekong Basin |
| UN REDD | United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation |
| USAID | United States Agency for International Development |
| VA | Vulnerability Assessment |
| WCS | Wildlife Conservation Society |
| WDI | World Development Indicators |
| WFP | United Nations World Food Programme |
| WHO | World Health Organization |
| WMO | World Meteorological Organization |
| WRI | World Resources Institute |
| WSSV | White Spot Syndrome Virus |
| WTO | World Trade Organization |
| WWF | World Wide Fund for Nature |

# TABLE OF CONTENTS


© Dan Rathbun

# 1 INTRODUCTION

## 1.1 USAID MEKONG ARCC PROJECT

The USAID Mekong ARCC project is a five-year project (2011–2016) funded by the United States Agency for International Development (USAID) Regional Development Mission for Asia (RDMA) in Bangkok and implemented by Development Alternatives Inc (DAI) in partnership with International Centre for Environmental Management (ICEM) and World Resources Institute (WRI). The project focuses on identifying the environmental, economic, and social effects of climate change in the Lower Mekong Basin (LMB), and on assisting highly exposed and vulnerable rural populations in ecologically sensitive areas increase their ability to adapt to climate change impacts on water resources, agricultural and aquatic systems, livestock, ecosystems, and livelihood options.

The USAID Mekong ARCC project includes five major technical initiatives in addition to overarching program management. These are:

1. The Regional Platform Partner and Knowledge Center,
2. The Climate Change Impact and Adaptation Study,
3. Ecosystem and Community-based Adaptation Initiatives,
4. Valuing Ecosystem Services in Economic Planning for the Lower Mekong River Basin, and
5. Scaling-Up Successful Approaches.

This report summarizes the results of the USAID Mekong ARCC project's second technical initiative, the Climate Change Impact and Adaptation Study for the Lower Mekong Basin (Mekong Climate Study).

## 1.2 MEKONG CLIMATE STUDY AND ITS OBJECTIVES

**The aim of the Mekong Climate Study is to undertake a climate change vulnerability and adaptation study on the water resources, food security, livelihoods, and biodiversity of the LMB.** The study is led by ICEM and the study team is made up of 21 international and regional specialists.

The Mekong Climate Study lays the foundation for the whole USAID Mekong ARCC project by providing the scientific evidence base for identifying highly vulnerable and valuable agricultural and natural systems assets in the LMB. It also defines broad adaptation options and priorities, and guides the selection of focal areas for enhancing existing approaches and demonstrating and testing new adaptation strategies. The study focuses on five themes: i) agriculture, ii) capture fisheries and aquaculture, iii) livestock, iv) natural systems, and v) socio-economics.

The objectives of the Mekong Climate Study are to take an ecosystems approach in:

1. **Identifying climate change impact and vulnerabilities** of rural poor and their environment—water resources, food security, livelihoods, and biodiversity (plants, fisheries, and wildlife);
2. **Identifying hotspots in the LMB** and providing a scientific evidence base to guide the selection of pilot project sites;
3. **Defining adaptation strategies for the main threats** to inform and guide community- and ecosystem-based adaptation pilot projects; and
4. **Communicating the results** of the vulnerability assessment and adaptation planning.

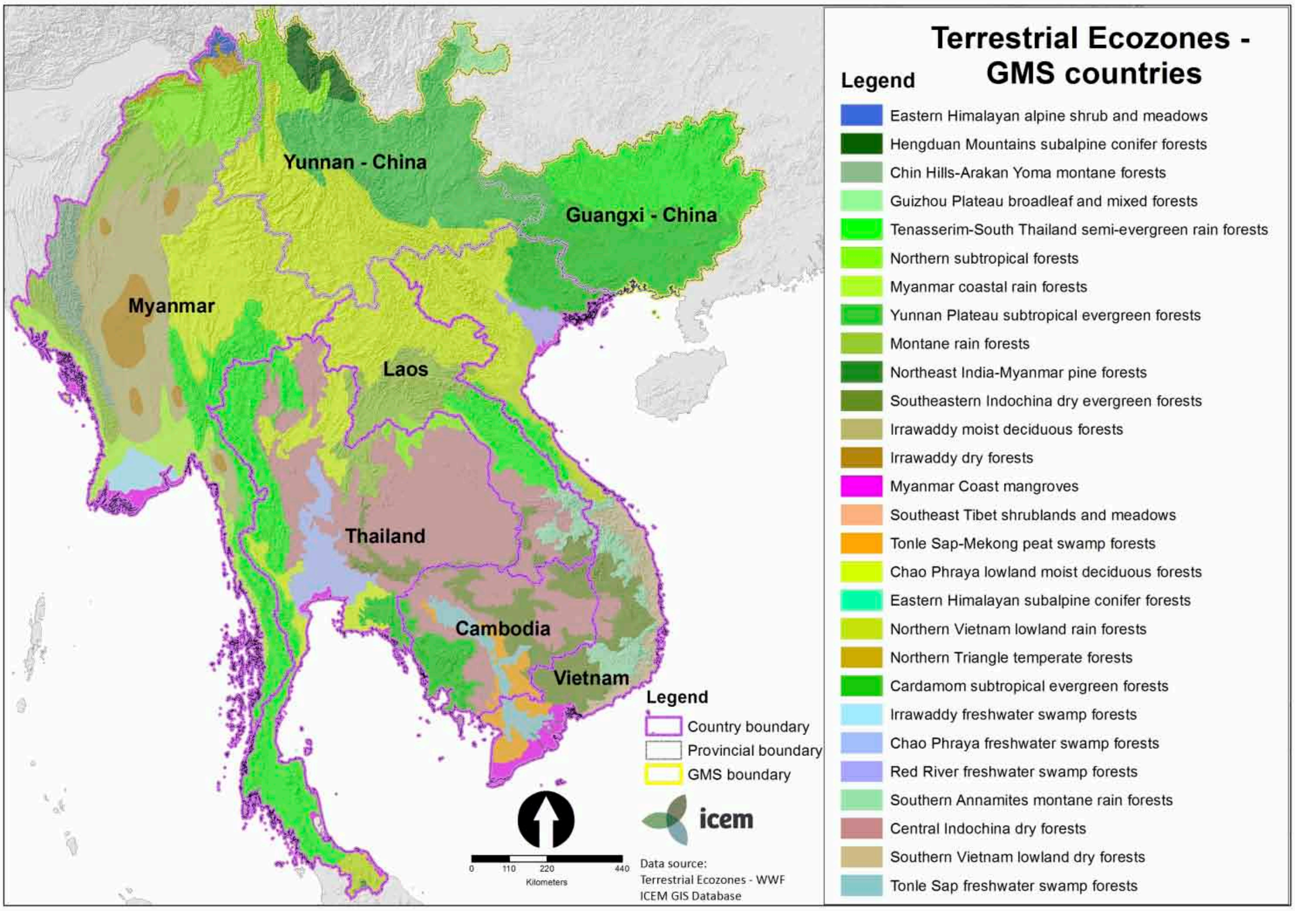
The Mekong Climate Study has taken an LMB-wide perspective. It starts by analyzing basin-wide climate changes and vulnerabilities according to ecological and administrative boundaries. It takes the vulnerability and adaptation responses to species and habitat level while maintaining the basin-wide context. Necessarily the adaptation strategies proposed provide broad guidance. The site-specific adaptation plans under subsequent USAID Mekong ARCC phases should be developed with guidance from local communities and government, incorporating local knowledge and tailored specifically to suit local conditions; as well as by drawing from the tool box set out in this Mekong Climate Study synthesis and additional theme reports.

# 2 THE LOWER MEKONG BASIN

## 2.1 BIOPHYSICAL OVERVIEW

**The LMB is a region of rich diversity—of landscapes, biodiversity, and ethnic and cultural diversity.** It lies in the Indo-Burma Biodiversity Hotspot with 12 of the World Wide Fund for Nature (WWF) Global 200 ecoregions, which are critical landscapes of international biological importance including: the Northern Indochina sub-Tropical Moist Forests, Annamite Range Moist Forests, the Indochina Dry Forests, the Eastern Himalayan Alpine and Meadows, the Eastern Himalayan Broadleaf and Conifer Forests, the Salween River, the Peninsular Malaysian Lowland and Montane Forests, the Cardamom Mountains Moist Forests, the Mekong River, and the Andaman Sea (Figure 2-1).

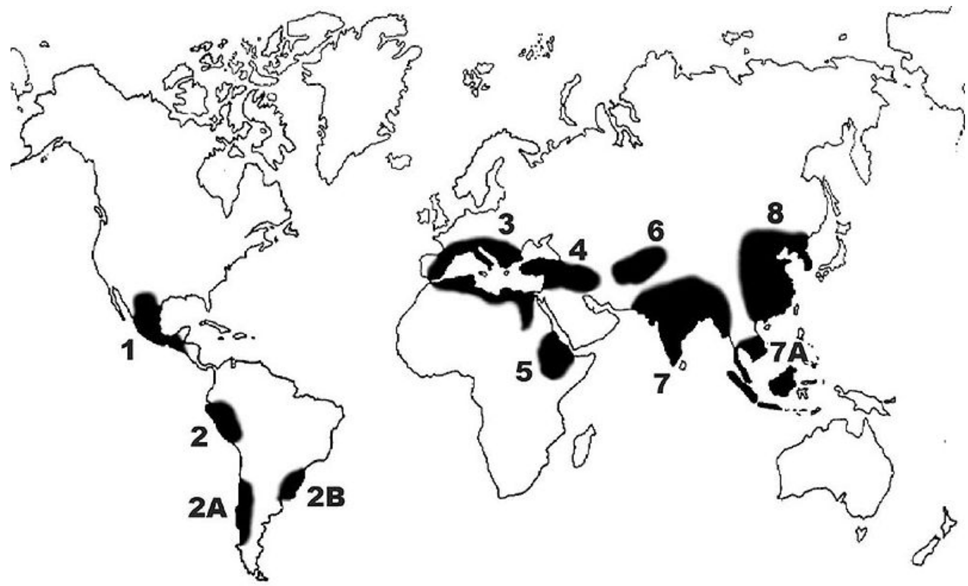
**Figure 2-1 Terrestrial Ecoregions of the Greater Mekong Subregion (GMS)**




**The region is one of the eight main Vavilov Centers where the wild relatives of most of the worlds domesticated plants originated** (Figure 2-2).[1] The Lower Mekong Basin lies in the Indian Center consisting of the Indo-Burma and Siam-Malaya-Java sub centers with 117 and 55 crop wild relatives (CWRs) respectively, including rice, eggplants, sugar cane, black pepper, mangosteen, and many others.

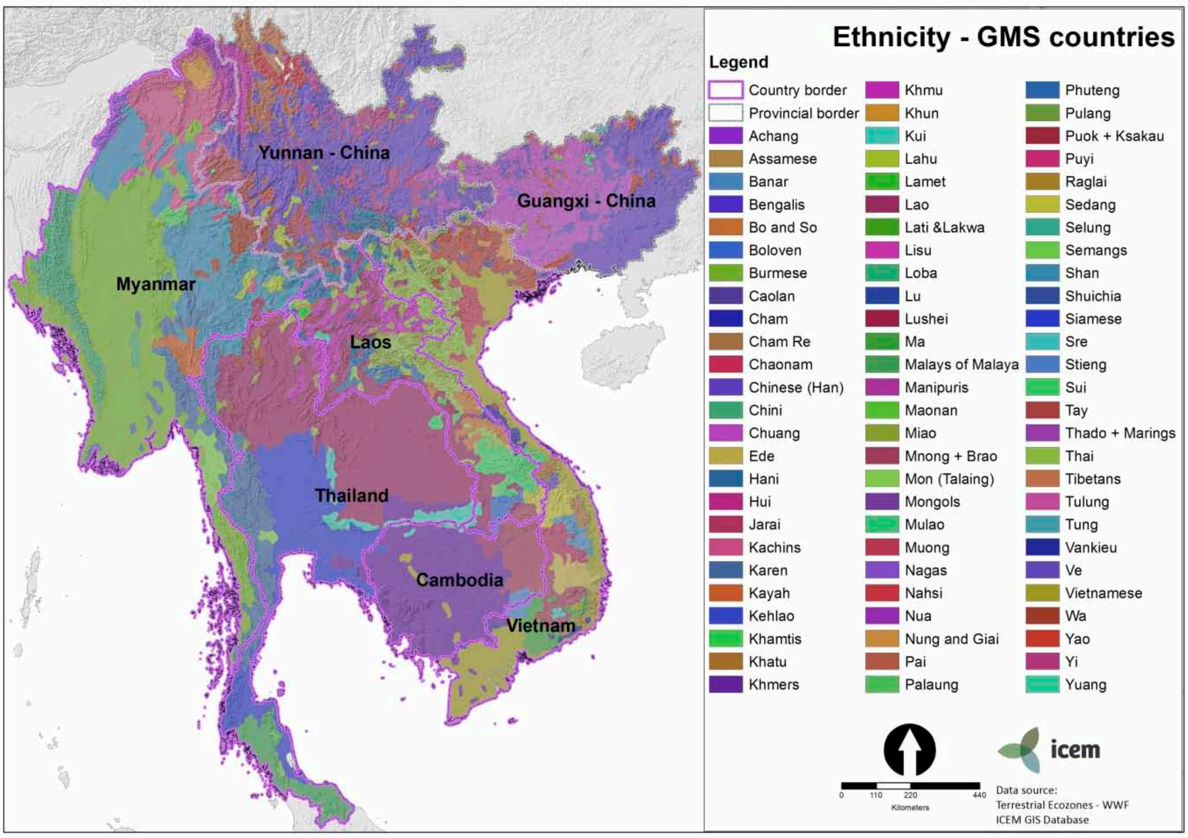
[1]A **Vavilov Center of Diversity** is a region of the world identified to be an original center for the domestication of plants. The center of origin is also considered the center of diversity. Vavilov Centers are regions where a high diversity of crop wild relatives can be found, representing the natural relatives of domesticated crop plants.

Figure 2-2: Vavilov centers of origin of domesticated plants




**The Mekong region is ethnically diverse with over 100 different ethnic groups** reflecting the diversity of their surrounding natural environment (Figure 2-3). Many of these ethnic groups have distinct languages, beliefs and cultural practices, including agriculture and animal husbandry, closely associated with the landscape and biodiversity of their area. For example, Lao PDR has over 13,000 recognized varieties of cultivated rice with different names and characteristics. The Mekong's vast ecosystem and species diversity underpins a wide variety of livelihoods and is the foundation for food security in the rural communities that make up about 85 percent of the basin's population.

Figure 2-3: Ethnic diversity of the Greater Mekong Subregion (GMS)



**The uniting force for this rich diversity is the Mekong River**, which rises in Tibet, flows down through China for about 2,500 km and then for another 2,400 km between Lao PDR and Myanmar, Lao PDR and Thailand, into Cambodia, and down to the delta in Vietnam. The total catchment area of the Mekong is about 760,000 $km^2$, including the upper catchment in China. The catchment area of the LMB is about 630,000 $km^2$ (63 million ha).

**The underlying heterogeneous geological structure is the major factor controlling the course of the Mekong and its landscapes** (MRC 2011). Unlike many other large rivers of the world which have simple dendritic tributary networks, the Mekong River basin is complex with different sub-basins having very different drainage patterns. In the Lower Mekong, from where the River leaves China, the main physiographic regions include:

- ***Northern Highlands***: the upland region of Myanmar, northern Thailand and northern Lao PDR.
- ***Khorat Plateau***: a saucer shaped basin at about 300 masl in northeast Thailand draining the largest tributaries, the Mun-Chi Rivers.
- ***Annamite Mountains***: the catchment to the east of the Mekong, and the boundary between Lao PDR and Vietnam.
- ***Central Highlands***: the source of the "3S" Rivers—Sekong, Sesan and Srepok—three of the Mekong's largest tributaries.
- ***Siphandone and the Khone Phapheng Falls***: At the border between Lao PDR and Cambodia and downstream of the Mun-Chi confluence, the Mekong enters a mixed alluvial-bedrock reach where the main channel fans out into a complex network of channels and islands before entering Cambodia through the Khone Falls—Southeast Asia's largest waterfall.
- ***Tonle Sap Basin***: The Tonle Sap is globally unique and one of Asia's largest inland lakes covering up to 15,000 $km^2$ in the wet season and shrinking to 2,500 $km^2$ in the dry season. Changes in its size are driven by extraordinary changes in the flow regime of the Tonle Sap River, which seasonally reverses flow direction. The catchment area of the lake comprises 13 low-gradient and low elevation tributaries circumscribed by the Cardamom Ranges, the Khorat Plateau and the 3S basins.
- ***Mekong Floodplain and Delta***: South of Kratie, the Mekong enters a broad alluvial floodplain of more than 72,570 $km^2$ including the Tonle Sap. Downstream of Phnom Penh the river enters the delta, and after the Cambodian-Vietnam border it splits into seven distributary channels which drain into the South China Sea.[2]

Originally, the Mekong region was covered in rich evergreen, mixed deciduous and dry dipterocarp forests. In 2005, the total forest cover in the Lower Mekong countries was about 540,000 $km^2$ (54 million ha, of which 48 million ha were natural forests, with only 8.3 million ha or 15% of primary forest remaining and 40 million ha of modified or secondary forests, and 6 million ha of plantations). At that time, most of the plantations were in Thailand and Vietnam where they made up about 20% of the forest cover. Since 2005, there has been significant increase in plantations in all four LMB countries.[3] Forests have been significantly impacted by human activities across the Mekong Basin. Few stands of primary forest remain, and the degradation, fragmentation, and conversion of secondary forest to alternate land uses and monoculture forest stands is widespread (Stibig et al. 2007, WWF 2013). Between 1973 and 2009, Cambodia lost 22% of its forest cover, 24% was lost in Lao PDR and 43% in both Vietnam and Thailand (WWF 2013).

---

[2] The Mekong once split into nine channels. At the beginning of the 20th century, the Bassac channel, which used to flow in the middle of the Cu Lao Dung isle in Soc Trang Province, filled with sediment. The Ba Lai channel in Ben Tre Province was dammed by the government in 1999 for salinity control.

[3] These figures on forest cover come from MRC (2011) State of the Basin report, quoting from FAO (2005) Global Forest Resources Assessment. Note that the forest coverage and extent is reported within the LMB countries as a whole, rather than the area of the basin alone.

Much of the natural forests in the Lower Mekong countries are located within protected areas of various kinds. There are close to 10 million ha of protected areas in the LMB, making up about 16% of LMB land area. In terms of total national land areas, Cambodia has 25%, Thailand 20%, Lao PDR 21% and Vietnam 6.2% of land covered by the national protected area systems. These are mainly terrestrial protected areas focused on forest ecosystems. Other forest areas include production forests and plantations.

**The Mekong forest landscape has been largely transformed for agriculture**, especially for rainfed and irrigated rice, the staple food of the region. More than 10 million ha of the LMB's total cultivated land is used to produce rice. Upland areas where the slopes can be steep have been cleared for shifting agriculture growing hill rice, maize and other subsistence crops. Commercial crops include coffee, cassava, soya bean and sugarcane. Rapidly increasing plantations of rubber are changing the landscape throughout the region. During the past two decades that ecological transformation of the basin has accelerated due to large scale infrastructure development such as hydropower and road networks which provide access to other resource uses.



**The biodiversity of the Mekong River Basin is of exceptional international conservation significance and a foundation for Mekong country economies and local livelihoods.** The region has some 20,000 plant species, 430 mammals, 1,200 bird species, 800 reptile and amphibian species and 850 fish species. Many new species are being identified—between 1997 and 2007 at least 1,068 new species were discovered.

The Mekong River is the largest riverine wetland complex in the region—at one time wetland ecosystems covered very large areas of the LMB. Those have now been converted to agriculture, especially rice paddy. Out of 254,000 km$^2$ of man-made and natural wetlands in the LMB, some 22% or 55,500 km$^2$ can be classified as natural wetlands. Most of the remaining man-made wetlands consist of rice paddy land. Of the natural wetlands about 80% are "wet" lands—i.e., marshes, bogs, swamps and flooded forests. The connectivity that the river and its tributaries bring to the wetlands of the Mekong through the seasonal flooding caused by the flood pulse is critical for the productivity and diversity of LMB fisheries.

**The Mekong supports the largest freshwater fishery in the world**, about 2.6 million tonnes (MT) per year in 2000, 1.9 MT coming from the capture fishery and the rest from aquaculture. Aquaculture production has been growing steadily. Close to 1 MT of aquaculture products are exported from the region. The people of the Mekong have the highest per capita consumption of fish in the world—up to 50 kg/head/year in some parts of the basin. Of the fish species nearly 200 species are migratory "white" fish, some of them travelling long distances from the Tonle Sap or the delta up the Khone Phapheng Falls and further up the Mekong in Lao PDR and Thailand. These migratory species make up a significant proportion of the fish caught. "Black" fish species move short distances between the main river and the floodplains.

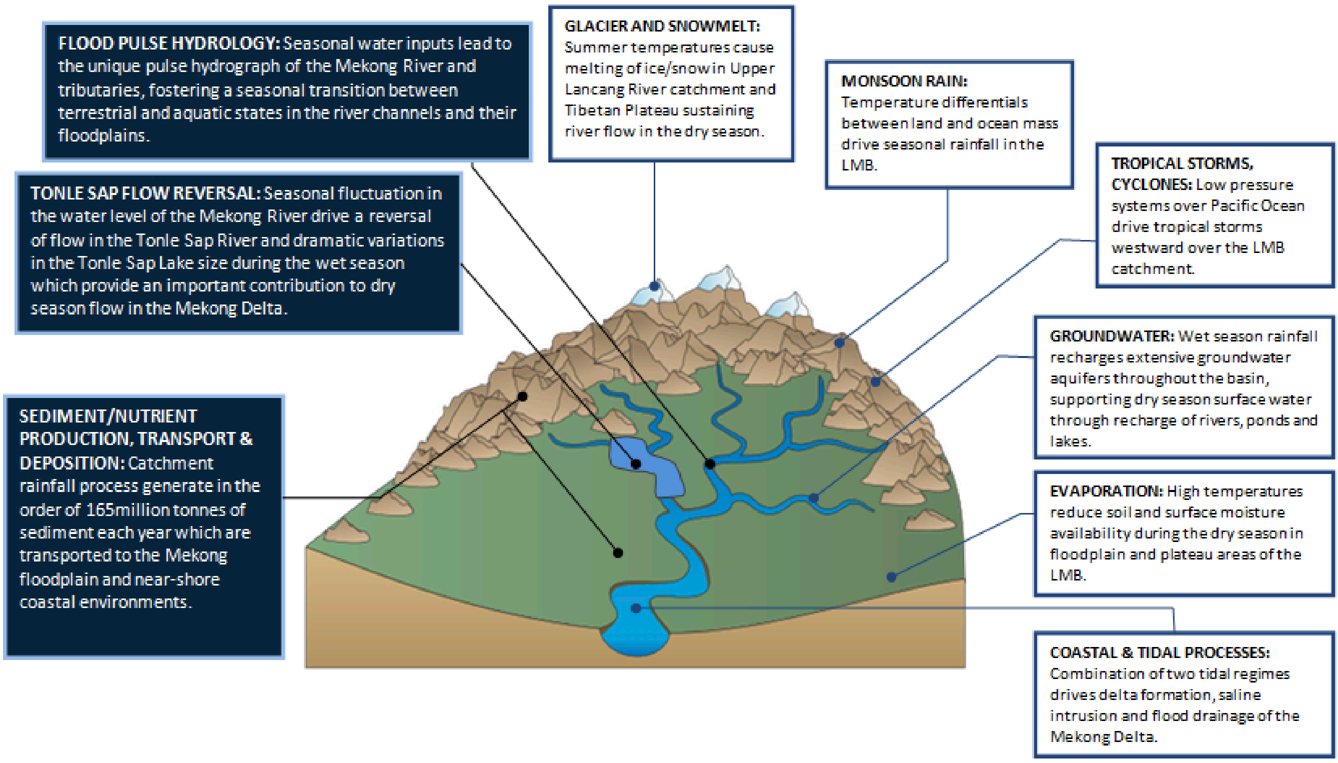
## 2.2 HYDROCLIMATE

**The diversity and productivity of the Mekong River Basin is driven by a unique combination of hydroclimatic[4] features** which define the timing and variability of water inputs, transport, and discharge through the watershed (Figure 2-4).

**The combination of two monsoon regimes is the fundamental driver of the Mekong hydroclimate**. The Indian Ocean monsoon occurs during the northern hemisphere summer when temperature differences between the land and the Indian Ocean force moisture laden air to precipitate over the Mekong's mountains. This monsoon divides the calendar year into the wet (May–late September) and the dry (October–late April) seasons. During the dry season, air flow over the Mekong is reversed as a high pressure system over the Asian land mass forces dry continental air flow over the basin, while the East Asian monsoon—originating in the Pacific Ocean—contributes minimal and erratic rainfall as most of the basin lies in the rain shadow of the Annamite Mountains (MRC 2011).



**Figure 2-4: Hydroclimate features of the Mekong Basin**




**The El Nino/Southern Oscillation (ENSO) is the dominant synoptic weather pattern affecting the Mekong Region. In the last 50 years there have been high levels of inter-annual variability in precipitation in the basin due to increased ENSO activity and variability in the East Asian monsoon** (Rasanen et al. 2013). Several synoptic weather patterns have been linked to the Mekong Region including ENSO, Indian Ocean Dipole, Madden-Julian Oscillation

[4] Hydroclimate refers to the covarying features of the linked climate – hydrological regimes of the Mekong Basin.

and Quasi-Biennial Oscillation. However, to date only ENSO has been shown to have a clear physical connection to climate in the Mekong (Delgado et al. 2012; Rasanen and Kummu 2013). El Nino years are associated with below average rainfall while La Nina years are linked to above average rainfall.

**Distribution of rainfall is highly variable throughout the basin along an increasing east-west gradient.** Highest rainfall occurs on the western slopes of the Annamites of Lao PDR and Vietnam, where mean annual rainfall can exceed 2,500 mm/year, while the majority of Northeast Thailand and the northeastern coastal region of the delta experiences less than 1,200 mm/yr. Under average conditions annual rainfall typically varies by less than +/-15%, while between wet and dry decades variability in rainfall can be as much as +/-30% (MRC 2011).

**Tropical storms and cyclones are a major contributor to Mekong regional rainfall**. Over the past 50 years more than 100 tropical storms and cyclones originating in the western Pacific have crossed into the Mekong Basin. Storm events can start as early as July in the northern LMB; are most common and intense during August–October through the Central Highlands/3S rivers basins and southern Khorat Plateau; and can occur as late as November–December in the Mekong Delta (Table 1). Storm intensities are greatest in August–September with the Central Highlands and Northern Annamites most affected.

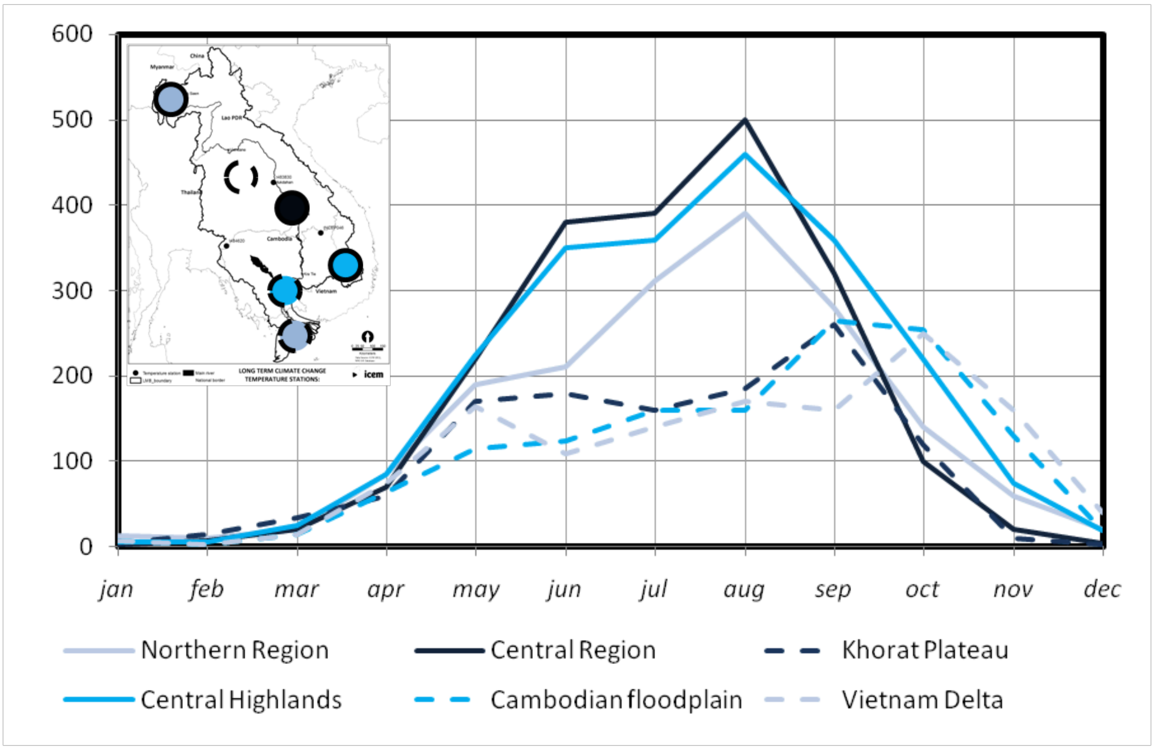
**Table 1: Historic distribution and timing of tropical storm and cyclone activity in the Lower Mekong Basin (1956–2009)** *(Source data: OCHA 2012)*

| Date | Intensity | Frequency | Landfall |
|---|---|---|---|
| **June** | + | + | Japan, Korea, China Eastern Seaboard |
| **July** | ++ | + | China, Northern Vietnam & Lao PDR |
| **Aug–Sep** | +++ | +++ | Northern & central Vietnam & Lao PDR – occasionally Thailand |
| **Oct–Nov** | ++ | ++ | Central Vietnam, Southern Lao PDR & Cambodia |
| **Dec** | + | + | Southern Vietnam |

**Seasonal rainfall distribution shows two distinct peaks, reflecting the interaction of monsoon and tropical storm inputs**. The onset of the wet season is rapid resulting in a leading peak typically in May–June, followed by a short lull in rainfall during July as the synoptic conditions of the monsoon weaken (Figure 2-5; MRC 2011). The second and larger peak occurs in August–September and represents the return of monsoon strength combined with the onset of the tropical storm season. The bimodal trend in seasonal rainfall is most pronounced in the Northern Annamites and Central Highlands and weaker in the Northern LMB (Figure 2-5). In the Khorat Plateau and the Mekong floodplains the main peak in rainfall is in September and as late as October in the delta.

**The combined effects of temperature and rainfall lead to strong seasonal reversal in the Mekong moisture budget which has shaped terrestrial vegetation characteristics**. Mekong temperatures are closely correlated to elevation typically averaging between 22°C and 28°C across the basin. High temperatures result in evaporation rates of 1,000–2,000 mm/year (MRC 2011), which when combined with the seasonal rainfall distribution result in at least 5-7 months of the year under moisture deficit. The deficit is most pronounced in the Khorat Plateau.

**Figure 2-5: Seasonal distribution of average rainfall in the Lower Mekong Basin (mm)**

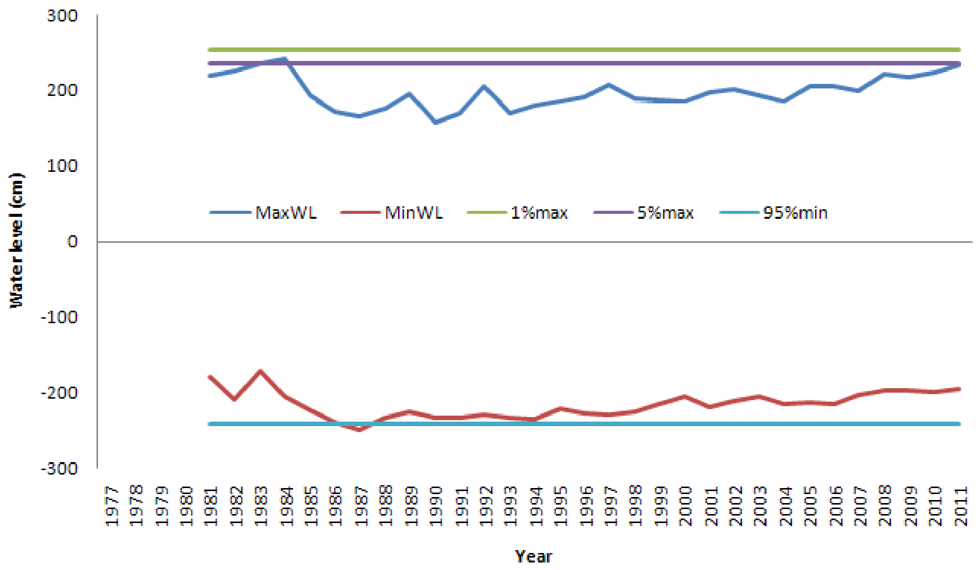



**Glacial and snow melt occurs only in the Upper Mekong Basin (UMB) but sustains surface water availability in the LMB during the dry season**. Though melt waters contribute only 16% to the mean annual flow in the Mekong River at Kratie, during the dry season the contribution is near 40%, while further upstream dry season flow contribution from melt waters can exceed 60% of the total flow (MRC 2009).

**Groundwater is also well connected with LMB surface water dynamics** recharging wetlands, lakes and fluvial river reaches during the dry season and absorbing substantial proportion of rainfall inputs during the wet season. There are four known major aquifer systems, though understanding of their size and the dynamics of surface connectivity remain poor.

**Tidal fluctuations influence wet season flood water levels as far upstream to the border between Vietnam and Cambodia, and drive saline intrusion upriver as far as Can Tho**. The Mekong Delta is under the influence of two tidal regimes; at the mouth of the main river channels tides can fluctuate by more than 4.0 m changing rapidly at an hourly time step (Figure 2-6). During the year, peak tides generally occur in October–March. High tide conditions during the dry season can reverse the direction of flow in the river channels as far upstream as Can Tho, driving saline intrusion 60 km inland. Saline intrusion is greater on the eastern coastline of the delta, due to larger tidal fluctuations. On average 1.4-1.9 million ha are affected for a period of 1-3 months (SIWRP 2009).

**Figure 2-6: Variability in maximum and minimum water levels at the Bassac River mouth (My Thanh) due to tidal fluctuations**



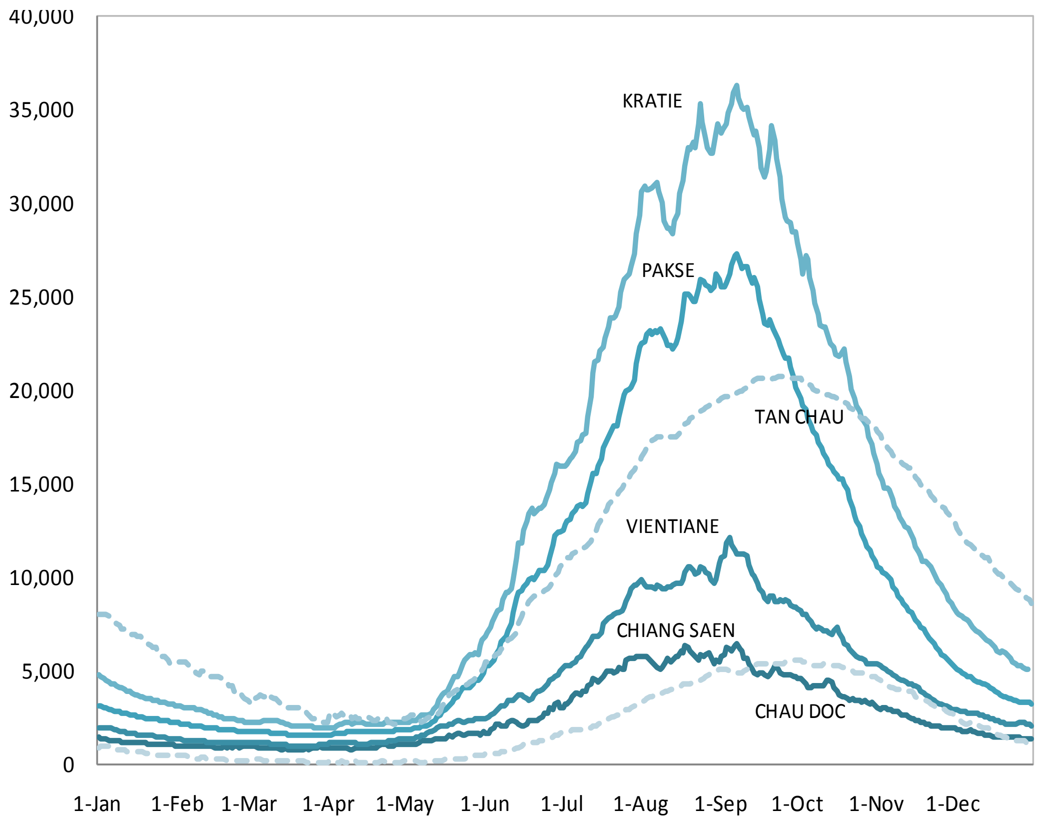

**The unifying hydrological feature of the system is the river's flood pulse, which is the result of individual rainfall-runoff events throughout the catchment coalescing into a stable and predictable hydrograph with distinct hydrological seasons** (Figure 2-7). Within the LMB, the Mekong flood pulse drives the river's high levels of aquatic and terrestrial biodiversity and system productivity (Kummu et al. 2007).

**The LMB tributaries are the main drivers of the peak in the flood pulse**. Approximately 59% of the Mekong's average annual flow originates from the left-bank tributaries in Lao PDR, Cambodia and Vietnam (ICEM 2010). The Upper Mekong Basin contributes 16% to the average annual flow, while the combined contribution from the right-bank tributaries (North and Northeast Thailand and the Tonle Sap tributaries) accounts for ~25% (ICEM 2010). During the wet season, flow provenance is dominated by northern Lao PDR, the Central Highlands and the central region of Lao PDR.

**The LMB flood pulse is comparatively homogenous upstream of Kratie**, with comparable timing and duration of seasons in most LMB mainstream stations. The stations that depict this typical hydrograph signature are shown in Figure 2-7 with the solid lines. The key features of the hydrograph are:

- **Large seasonal variation in the flow regime**: Flow volumes peak in September approximately 4-6 weeks after the peak in runoff. Subsequent minimum dry season flows are on average 7% of the maximum wet season flows with the seasonal variation reducing further upstream.
- **Predictable flood peak:** On average, the flood season at all stations between Chiang Saen and Kratie begin on the 1st of July and last until the 4th–11th of November, with a standard deviation of 2 weeks (Adamson 2005).
- **High flow variability at the onset of the flood season:** Comparably high variability in flow during the transition season as the first rainfall events induce a series of *spates* into the hydrograph which play an important ecological role in triggering response in aquatic biota.

**Figure 2-7: The Mekong flood pulse at six mainstream stations:** *seasonal variability in climate results in a characteristic and stable pulsing signal in the Mekong hydrograph and fosters an immense annual transition of floodplain environment from terrestrial to aquatic. Units are m³/s. (Source: ICEM 2010)*




**Flood pulse dynamics are more complex and less predictable in the Mekong floodplains of Cambodia and Vietnam**. Downstream of Kratie the Mekong system shifts to a complex floodplain environment and there is significant variation in the hydrograph form compared to upstream. Representative hydrographs for the downstream stations are shown with the dotted lines in Figure 2-7. Key features of the floodplain include:

- **Reduction in the flood peak discharge:** Flows become less constrained to the Mekong channel and spread out over the floodplain with a corresponding reduction in flow and water level in the channel.
- **Lag in flood recession:** Flow is driven by water levels in the floodplain rather than channel flow, with the recession of overbank floodwaters and storage of floodwaters in the Tonle Sap Lake prolonging the flood season into January/February. Overland flow accounts for approximately 30% of the flood flow into the Mekong Delta (SIWRP 2006).
- **Higher daily variation in flows:** The complex hydrodynamics also cause greater fluctuation in water levels at a daily and weekly time step.
- **Cyclical variation in flood volumes:** Annual flood volumes entering the Mekong floodplain and delta typically vary by +/-10%. Under extreme conditions high flood years can be +40% above the average or -60% below in dry years.

**Low channel slope and the high variation in Mekong River water levels induce a seasonal change in the direction of flow in the Tonle Sap River allowing the Tonle Sap Lake to store**

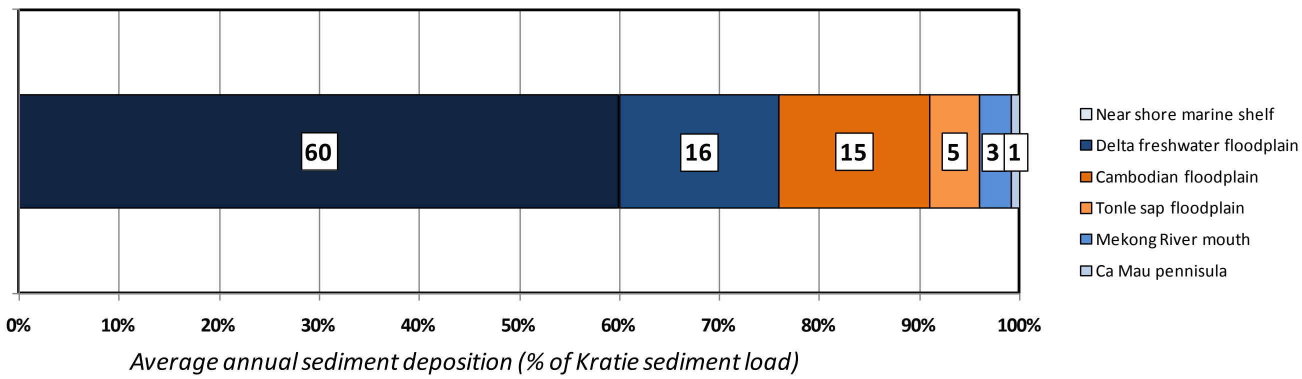
**an average 80 km³ of water each year.** Water flows toward the Mekong mainstream during the dry season and reverses direction during the wet.

- **Wet season (May–September):** Water levels in the Mekong rise approximately 9 m at Phnom Penh providing a hydraulic gradient that reverses flow up the Tonle Sap River into the lake with peak inflows reached typically three months after flow reversal. On average 80 km³ of water flows into the Tonle Sap Lake via the river and overland flow across the floodplain, representing 25% of the August flows in the Mekong (MRC 2006).
- **Dry season (October/November–April/May):** Water levels in the lake are elevated by 6-9 m at the beginning of the dry season and as the Mekong floodwaters begin to recede the hydraulic gradient reverses direction with flow resuming the natural direction. Flow reaches 10,000 m³/s in just a few weeks, returning ~87% of the lake volume to the Mekong (MRC 2007). The Tonle Sap return flow plays a critical role in maintaining dry season freshwater environments in the downstream Mekong Delta.

**The Mekong hydroclimate plays a critical role in landscape processes, driving sediment production in the upper catchment and transporting it downstream to fulfil a multitude of geomorphological and productivity functions**. On average, the annual sediment load at Kratie is roughly 160 MT/yr (140-180 MT/yr), with approximately 50% to 60% originating from China. The 3S catchments in the southeastern portion of the LMB contribute ~17MT/yr equivalent to ~10% of the total load, while the remainder of the basin is estimated to contribute 30% (Sarkkula et al, 2010). Land clearing, hydropower and soil conservation strategies have influenced the annual average sediment loads—especially in the Lancang or Chinese portion of the catchment area (ICEM 2010).

Attached to Mekong sediments are a minimum of 27,000 tonnes of phosphorus based nutrients. The deposition of sediments and nutrients in the floodplain and marine environments contribute to river channel and delta stability as well as fertilize floodplain and aquatic environments allowing the floodplain to support a vast array of agro-ecological productivity. Estimates for the proportionate deposition of the Mekong sediment load in the key floodplain environments are given in Figure 2-8.

**Figure 2-8: Mekong floodplain and delta sediment deposition:** *estimates of proportional distribution of Mekong sediments in the six main regions of the Mekong floodplain and delta. (Adapted from: ICEM 2010)*



## 2.3 SOCIO-ECONOMIC OVERVIEW

The LMB supports around 65 million people, most of whom are dependent on agriculture and natural resources. The region is in a state of flux: economic expansion and demographic shifts are transforming the economies and environment at a pace and scale never before experienced. Yet, poverty and food insecurity remains entrenched in many parts, even in relatively prosperous Thailand and Vietnam. Natural resources are essential to rural livelihoods—for the poor that dependence is likely to increase in the coming decades. This reliance reflects the acute sensitivity of rural households to adverse weather events, such as floods and droughts, as well as to degradation of the natural environment.

A significant feature of the LMB's demographic landscape is the degree of diversity across socio-economic indicators. While population growth continues to accelerate in Cambodia and Lao PDR, sharply declining fertility rates from 1970 to 2000 have seen the populations of Vietnam and Thailand begin to plateau. In broad terms, the status of poverty, food security, and other livelihood indicators are more favorable in Vietnam and particularly in Thailand compared to Cambodia and Lao PDR. These distinctions reflect the relative stages of economic development across the region. Those gaps are narrowing as the two less developed LMB economies expand rapidly. Although marked disparities exist, some striking features are evident throughout the region:

**The rural poor are heavily dependent upon ecosystem services.** This is the case across livelihood activities relating to agriculture, fisheries, livestock and non-timber forest products (NTFPs). Poor rural families in Cambodia, for example, have some 80% of their livelihood activities linked to forest and aquatic resources. Threats to the provision of these ecosystem services, such as climate change and major infrastructure projects have large development and livelihood impacts. In terms of food security, fisheries are the critical source of protein, even in remote upland areas away from large fisheries. In Lao PDR and Cambodia, a surge of infrastructure developments and commercial land concessions are reducing forests, rivers and wetlands in their natural state and the resources and services they provide to rural communities.

**A diversified portfolio of livelihood activities is the norm for rural households.** That diversity provides flexibility in recovering from extreme events. A discrete shift in the productivity of one sector may be offset by increased production in other sectors such as the use of forest food products as a contingency measure when crops fail. Yet, a trend of unsustainable harvesting of those forest foods is reducing their long-term availability.

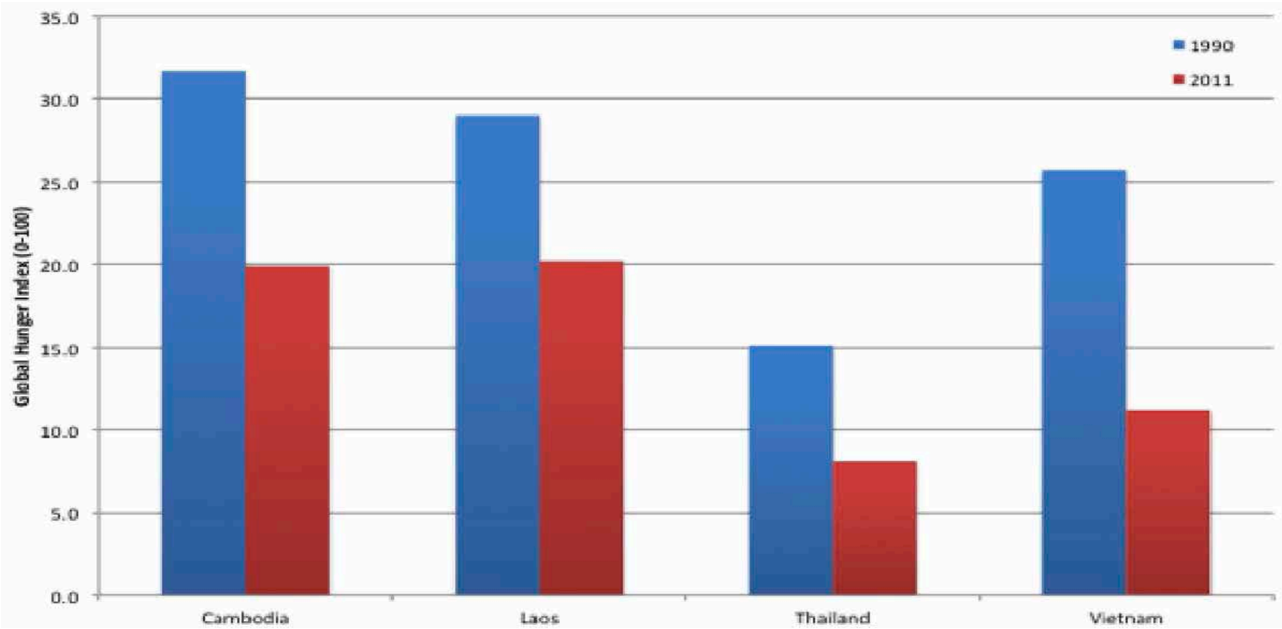
**There is a general shift towards greater commercialization of agriculture**, with even smallholder subsistence-based households engaged in some form of commercial activity. This trend carries risks in terms of increased exposure to price shocks and environmental degradation, but also affords opportunities such as improved crop varieties.

**Migration is increasing across the region in search of land, resources and employment.** Three types of migration prevail: (i) rural-urban migration, the most significant type but one that can be highly temporary and seasonal; (ii) transboundary migration, driven partly by significant diaspora of fellow nationals or ethnicities in neighboring countries; and, (iii) rural-rural migration, driven by the desire to access natural resources (particularly land in forest areas) and displacement due to land concessions and development projects.

**All countries contain particular groups who remain chronically poor or are vulnerable to falling into poverty and food insecurity.** Great progress has been made to reduce poverty and food insecurity across the region. Yet, income growth masks the tendency to regress, particularly following strong external shocks like extreme floods and drought. Even households that have moved beyond a marginal existence and possess productive assets such as irrigation infrastructure and farm machinery have much to lose from reduced access to natural systems and resources.

**Food security** is an important consideration throughout the basin, particularly for rural populations. Aggregate measures of hunger or child malnutrition indicate substantial declines in food insecurity in recent decades (Figure 2-9).

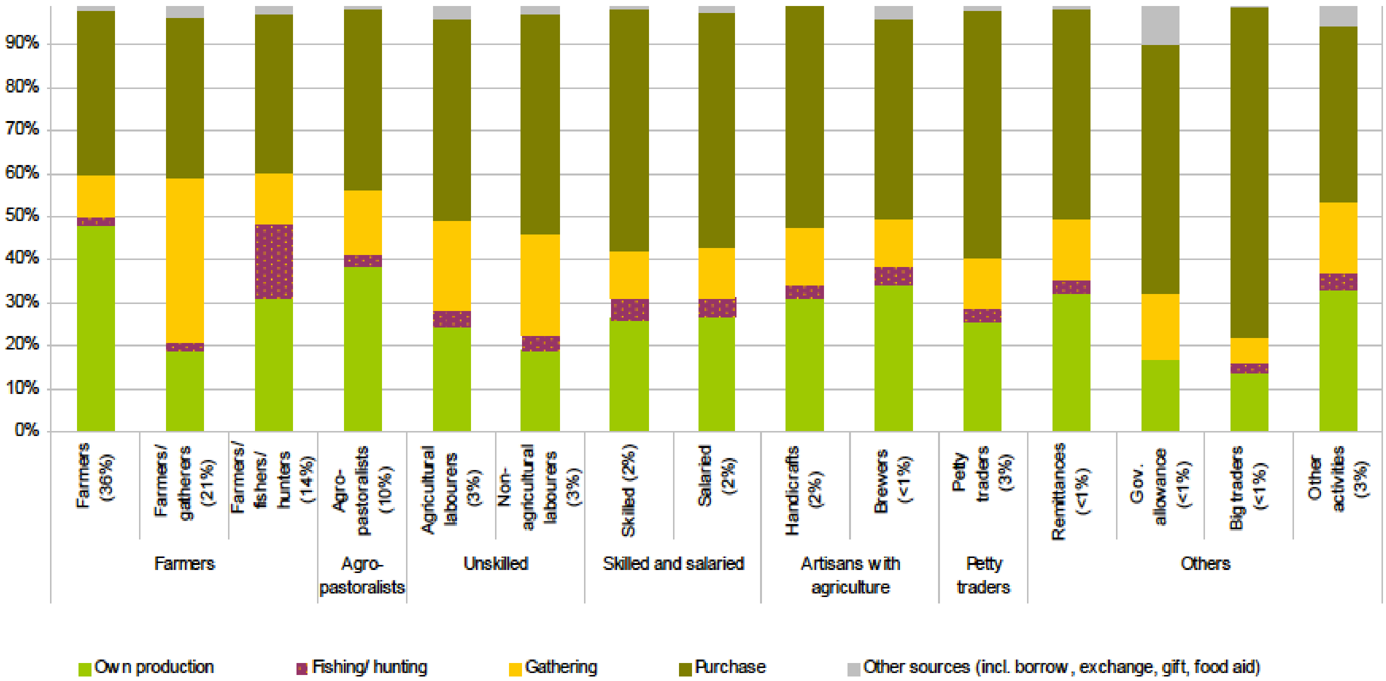
**Figure 2-9: Food security in Lower Mekong Basin countries, 1990 and 2011**




*Source: IFPRI 2011*

However, those aggregate trends obscure important differences in food insecurity among different groups. Different communities in the same country or province pursue different livelihood activities according to their resource endowments, as do different members of the same community. Households are exposed to shocks of variable magnitude in different sectors. For example, Figure 2-10 documents food sources by occupation for a sample of Lao PDR households. Farmers are more heavily dependent on their own produce and are likely to be more exposed to a crop disease than a farmer/gatherer.

**Figure 2-10: Food source by occupation (Lao PDR 2007)**




*Source: WFP 2007*

Figure 2-10 also demonstrates some important similarities across groups that can be generalized to most rural communities across the basin:

- **Livelihood portfolios are highly diverse**. Regardless of principal occupation, all households are engaged in a range of activities. This observed diversity underlines the importance of considering the linkages between sectors. If the productivity of one sector weakens, a household is likely to seek productivity gains or increased production in another sector.

- **Subsistence-based fishing is a common livelihood activity of most households across rural areas of the LMB**. Figure 2-10 shows that subsistence-based fishing (and hunting) is a common secondary activity across all occupations. As fisheries are the key source of protein in the basin, households are sensitive to changes in the productivity of fisheries systems. In Cambodia, fish provide at least 75% of protein intake in every province, and around 95% for those around the Tonle Sap (MRC 2010). These trends are apparent throughout the basin, even in upland areas.

- **Natural systems are critical to food security.** Looking across the different groups listed in Figure 2-10, farmers, agro-pastoralists and other groups constituting 98% of the total sample were all between 40% and 60% dependent upon some combination of subsistence farming, fishing/hunting and gathering. These are all productive sectors that are heavily dependent on healthy ecosystems.

- **Marketed food is important to subsistence-based households.** Almost all households are engaged in some commercial activities and are therefore susceptible to price shifts in the market-place and/or external food shortages.

## 2.4 TRANSFORMATION OF LMB FARMING SYSTEMS

**LMB's farming systems are being transformed through a continuing shift away from labor-intensive, subsistence-based agriculture** (MRC 2010, Johnston et al. 2009). That shift has significant socio-economic implications, particularly for the vulnerability of rural communities to climate change.

### 2.4.1 COMMERCIAL AND SUBSISTENCE AGRICULTURE

Figure 2-11 summarizes the major characteristics of LMB commercial and subsistence agriculture. A third category (not shown) is also common in the basin: smallholder commercial agriculture, which represents a mixture between the two main types, but this farming still occurs on a relatively small-scale and with some subsistence activities.

In the LMB there are examples of both full-scale commercial agriculture (e.g., large plantations of non-food crops such as rubber, cassava and coffee) and the purest forms of subsistence agriculture (e.g., shifting cultivation). Most rural households and communities lie somewhere in between.

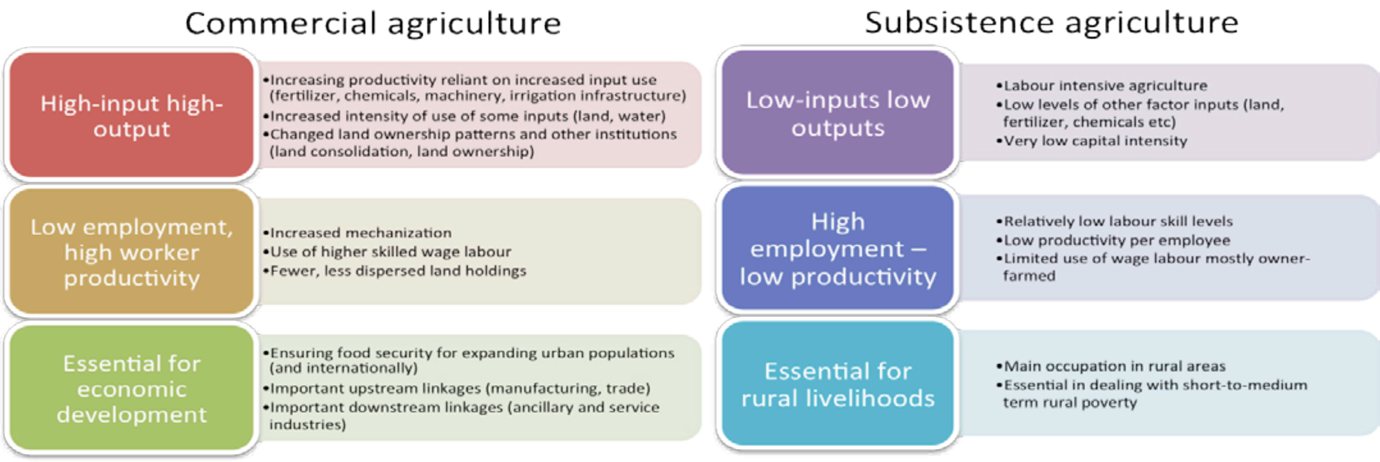
The diversified nature of rural farming systems means that even the remotest subsistence-based communities have opportunities or need to conduct commercial activities at least some of the time. Whether commercial or subsistence-based, all farming systems and sectors have one thing in common: their productivity is dependent on healthy, functioning natural ecosystems.

### 2.4.2 AGRICULTURAL PRODUCTION IN THE LMB

Three main trends point to the rise of commercialization in the region: (i) agricultural exports have risen rapidly, (ii) harvested areas of most key commodity crops have also risen rapidly, and (iii) upward, though not necessarily uniform, trends in yield have occurred in all major commodities.

Across LMB countries three broad phases of agricultural commercialization can be observed: a large, relatively advanced agricultural sector in Thailand; a smaller, but established and growing commercial sector in Vietnam; and, the relatively recent emergence of commodity production in Cambodia and Lao PDR. The rate of development is not uniform within countries: subsistence and smallholder communities occur throughout Thailand and advanced commercial farming operations exist in Lao PDR.

**Figure 2-11: Characteristics of commercial and subsistence agriculture**




In Thailand and Vietnam, the emergence of commercial agriculture has followed capitalist-oriented policy reform and broader economic development. In Lao PDR and Cambodia, commercialization is largely driven by government policies that focus on attracting private, often foreign investment in economic land concessions (Johnston et al. 2009).[5]

[5] This is exemplified by the Lao PDR government's estimate of the area of agricultural land concessions (excluding contract farming): 5.5% or 1.1 million ha, which is more than the total land area growing rice and officially recognized as probably being an under-estimate (Schönweger et al. 2012).

The upward trajectory of regional population, urbanization, and income growth is also driving rising food demand. Moreover, the diets of a wealthier population are shifting towards the consumption of more resource-intensive meat and dairy products. These shifts will provide demand for further productivity improvements and further commercialization. Other external factors will also drive this shift in the future, for example, China's demand for agricultural imports and the evolution of global commodity prices.

### 2.4.3 SOCIO-ECONOMIC IMPLICATIONS OF COMMERCIAL AGRICULTURE

**Over the long-term, the LMB agricultural transition has positive implications for the alleviation of poverty and the provision of food security**. For LMB countries, rising agricultural productivity is a major engine of economic development (Ryan 2002, Timmer 2000). A stable food supply, foreign exchange earnings, higher savings, and greater demand for industrial sector goods, as well as the shift of labor to industry: these are all critical elements of the broad economic development which is an integral part of poverty reduction.

Yet, in the short to medium term, the commercialization of agriculture poses significant threats to the security of the rural poor (von Braun 1995, Pingali 1997). Three main factors determine the welfare implications of the transition as presented by Pingali (1995):

(i) **Availability of alternative livelihoods and labor mobility** – Affected communities need to either engage in commercial agriculture or find wage employment elsewhere. The first choice presupposes adequate access to the requisite skills and investment capital; the second is contingent on adequate employment opportunities and, once again, necessary education and skills to obtain that employment.

(ii) **Land tenure** – Land is often the only asset subsistence communities possess. Commercialization generally involves a process of land consolidation and transfer of tenure to commercial enterprises. The capacity to effectively sell tenure rights or be otherwise compensated is therefore critical to welfare outcomes.

(iii) **Food security and relative prices** – In terms of net food security, the benefits of commercialization are contingent on the extent to which households are able to earn higher-level cash incomes relative to the market price of food.

**The transition to commercial agriculture frequently fails to enhance livelihoods in the short-term.** For example, a survey of villages adjacent to agricultural land concessions in Northeast Cambodia (Prachvuty 2011) found that: (a) only 16% of families received compensation for loss of land and most of those felt that compensation was inadequate; (b) only 30% of remaining families had since taken employment with the concession company; and (c) 92% of families believed they were worse off. Their reduced well-being was due to loss of shifting agricultural land and other farmland, loss of forest lands where they previously collected NTFPs, and land degradation from forest loss.

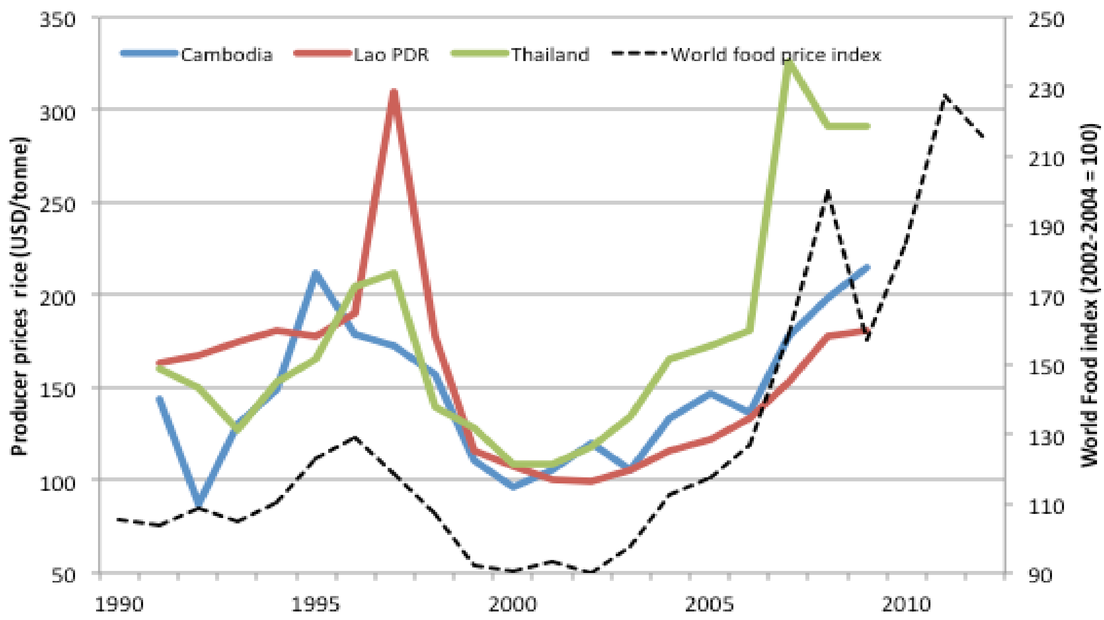
A transition from subsistence to, for example, contract-based farming has improved welfare elsewhere in the LMB (Setboonsarng et al. 2008). Yet, in most areas of Cambodia, Lao PDR, and Vietnam, many factors are making the transition disadvantageous to the rural poor. Absence of strong land tenure is one influencing factor. Another is the lack of skills to adapt; this is particularly prominent among ethnic minorities living in remote areas with poor access to state services.

Price risks are a challenge for three reasons: (i) low income households are more vulnerable to price rises—this is of particular concern with increasing real food prices and food price volatility (Figure 2-12); (ii) smallholder commercial farmers may be exposed to the significant swings in international commodity markets for their produce (Figure 2-12); and (iii) input prices, such as fertilizer costs, may also be subject to volatility.

Another critical issue is environmental sustainability. Central aspects of the shift to commercial agriculture include increased application of fertilizers and pesticides, irrigation diversions, more intensive cultivation of land, and clearance of forestlands. Natural resources are the foundation of rural welfare. The degradation of water supplies, soil erosion, and loss of access to NTFPs all have direct and immediate welfare impacts. Recent history highlights numerous cases in the LMB where the transition to commercialization has represented a worsening or the onset of environmental problems which are affecting the poor disproportionally (e.g., Johnston 2009).

There are also immediate opportunities from the transition. Rising labor productivity could and should raise incomes and living standards for at least some groups during the early stages of the transition. The creation of input supply chains and extension services, such as credit facilities should benefit smallholder commercial farmers. Similarly, the creation of stronger, non-local food trade provides insulation from localized natural disasters or adverse crop conditions.

**Figure 2-12: Food price fluctuations**




*Source: FAOSTAT (2012)*

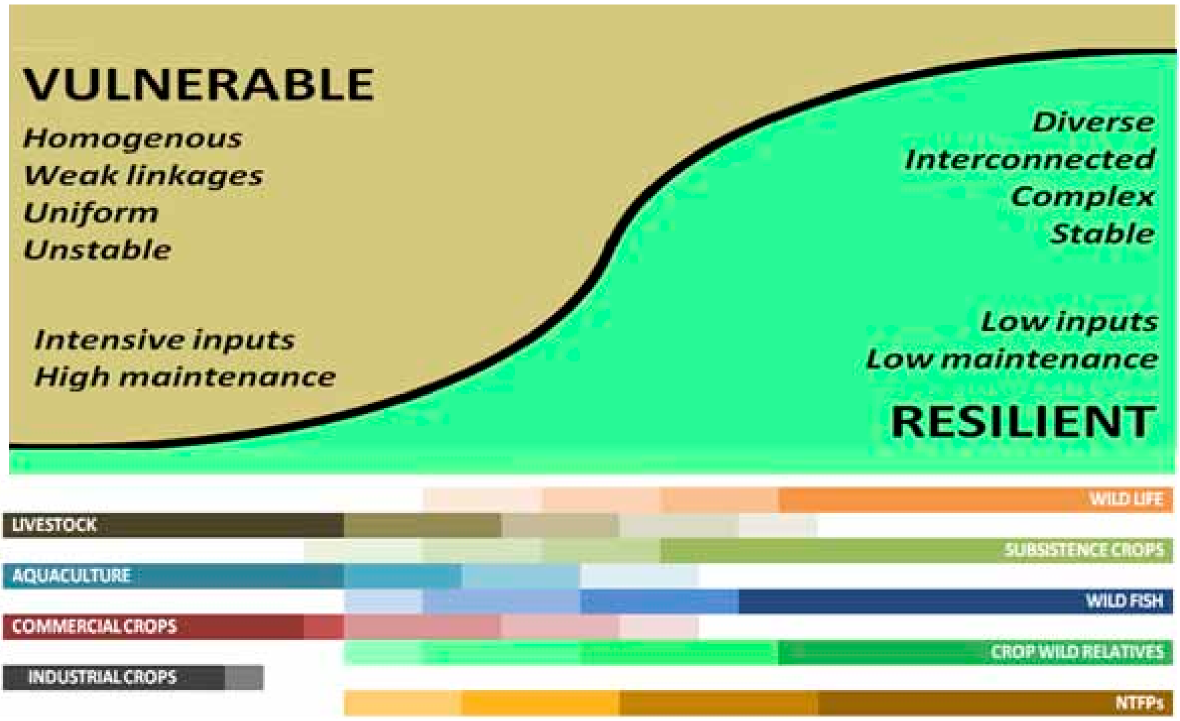
### 2.4.4 RISKS AND OPPORTUNITIES WITH CLIMATE CHANGE

**The agricultural transition exacerbates the risks posed by climate change for vulnerable groups, particularly in the case of extreme events.** Although climate change is a long-term process of incremental change in regular climate patterns, the LMB is projected to experience increased magnitude and frequency of extreme events such as floods and drought which can occur at any time.

Resilience to climate change in local communities could be built where commercialization increases access to markets, education, health services, and overall community welfare. For the individual household, the balance of risks and opportunities is highly context-specific. Yet, the negative implications of agricultural transition tend to increase the vulnerability of rural poor to extreme events.

From a systems perspective, the higher vulnerability of commercial farming systems is more clear-cut. Figure 2-13 consolidates all of the issues discussed in this section. On the right hand side we have subsistence-based agricultural systems and more extensive remaining natural systems; on the left we have commercial-based systems and more extensively modified ecosystems.

**Figure 2-13: Agro-ecological systems and climate change vulnerability continuum**




The most important point illustrated by the continuum is that most LMB farming systems are a complex mix of natural resource dependency and more intensive and sometimes commercial activities. That mix is likely to continue for most LMB farmers for several decades.

Farming systems tend to simplify and intensify as they shift from subsistence to commercial footing. Commercial systems are heavily dependent on a few inputs and highly sensitive to their fluctuations or failures. Subsistence systems tend to be more complex and a failure in one component can be substituted by another.

The different circumstances of two production systems illustrate those points—one intensively-farmed pigs and the other subsistence use of wild pigs. The risks of major productivity losses or cost increases are great in the intensive pig farm if, for example, (i) the price of commercial pig fodder changes, (ii) there is a rapid outbreak of disease, or (iii) there is a heat wave that farm facilities are not designed to accommodate. The subsistence-based system is more resilient because: (i) it is not dependent on fodder, (ii) wild pigs are more resistant to disease outbreaks, and (iii) wild pigs are able to move to cooler habitat in heat wave conditions. Similar comparisons can also be made for subsistence capture fisheries versus aquaculture or harvesting of NTFPs versus industrial crops.

Subsistence-based systems are inherently integrated with natural systems and benefit from their diversity and resilience to climate related shocks. However, natural systems are degrading in the LMB, partly due to the shift from subsistence to commercial agriculture. As farming systems move along this continuum they are becoming less diverse, more intensive, and less resilient to climate change without substantial maintenance and inputs to keep them stable.

Generally, this shift in farming ecosystems is taking place on a localized, gradual, and incremental basis as individual farmers seek more productive and profitable crops and methods. Yet, there are signs that it is beginning to occur rapidly and over larger areas. Clear-felling of forests to make way for large industrial plantations and expansion of concession areas to cover large proportions of Cambodia and Lao PDR are accelerating the shift along the continuum. These abrupt changes, or system leaps, greatly intensify the vulnerability of affected communities.

# 3 MEKONG CLIMATE STUDY METHOD

## 3.1 OVERALL METHODOLOGY

**The study overlaid projected climate and hydrological change on the current status and trends in the key livelihood sectors of the LMB**—agriculture, capture fisheries and aquaculture, livestock, natural systems, and health and rural infrastructure. An assessment of impact of climate change on those sectors enabled the study to estimate the vulnerability of areas and of species and habitats important to local communities and national economies. Experience within the region and in other parts of the world, and expert judgment and consultation through stakeholder workshops shaped the broad adaptation options identified by the study team. They are set out as categories or a menu of adaptation measures to guide the focused demonstration projects which will follow in the USAID Mekong ARCC project's subsequent phases.

For each sector or theme a technical group was formed of international and riparian specialists. The theme groups met together at each of the main vulnerability assessment and adaptation planning stages of the study to define the overall methodology and to discuss and integrate results.

### 3.1.1 METHODOLOGICAL CONCEPTS

The study has developed a number of key concepts to facilitate understanding and assessment of the vulnerability of livelihoods in the basin and to assist definition of adaptation responses (Figure 3-1). Those concepts include overarching guidance on the theoretical and spatial approach to the study down to details such as developing models of physical properties such as soil water availability and crop yields.

#### 3.1.1.1 Ecosystem-based approach

**The study has taken an ecosystem-based approach** to assess the impacts of climate change on livelihoods and to define adaptation responses to those impacts. ***An ecosystem-based approach is the integrated management of land, water, and living resources to promote conservation and equitable sustainable use.*** To be consistent with the ecosystem-based philosophy the study analysis of livelihoods has considered the interactions between the plants and animals that sustain livelihood activities within farming ecosystems. ***Farming ecosystems include the farm households, their assets and fields, and the surrounding natural systems from which they harvest provisions and receive services.*** The study's ecosystem-based approach recognizes:

- the importance of relationships between all parts of the farming system and its surrounding environment;
- the distinctive character and tolerance levels of each ecosystem to change;
- the different spatial levels of ecosystems which are important to farming system health and productivity (from soil to ecozone);
- the services that assemblages of wild species and other natural resources provide to farming systems; and
- the importance of healthy ecosystems as the foundation for adaptation in farming systems.

**Figure 3-1: Key methodological concepts developed by the study**

**Ecosystem approach**
- Recognises that farming ecosystems are linked with natural systems in a fabric across landscapes

**Shifts**
- Climate shifts, ecosystem shifts, farming systems shifts

**Zones**
- Ecozones and livelihood zones

**Climate change hotspots**
- Ecozones, sub-catchments, provinces, protected areas

**Comfort zones**
- Species and ecosystems

**Water availability index**
- Combination of rainfall, evapotranspiration and surface water flow to develop soil water availability index

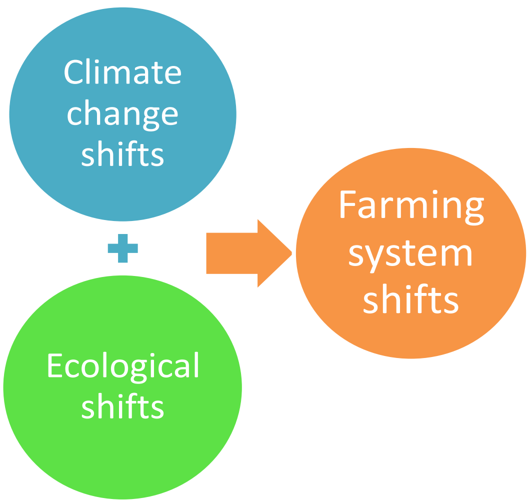
**Suitability and crop yield**
- Climate suitability for crops under climate change and crop yields under climate change

#### 3.1.1.2 Shifts

The concept of shifts is important when analyzing the potential impacts of climate change because often changes are incremental rather than clearly discernible steps. ***A shift is when a system or component of that system changes in state or location to accommodate changes in global and local climate.*** For this study the team focused on three types of shifts in the LMB—climate change shifts, ecological shifts, and farming systems shifts (Figure 3-2).

**The concept of climate shifts is a necessary simplification of the complexity of climate change threats and opportunities to allow for assessments of impact**. In reality climate change is multifaceted and does not simply lead to a shift of ecosystems to other regions. However, to understand potential impacts on equally complex natural systems the study distilled climate change into a few parameters and associated shifts that are connected to changes in natural systems and their components.

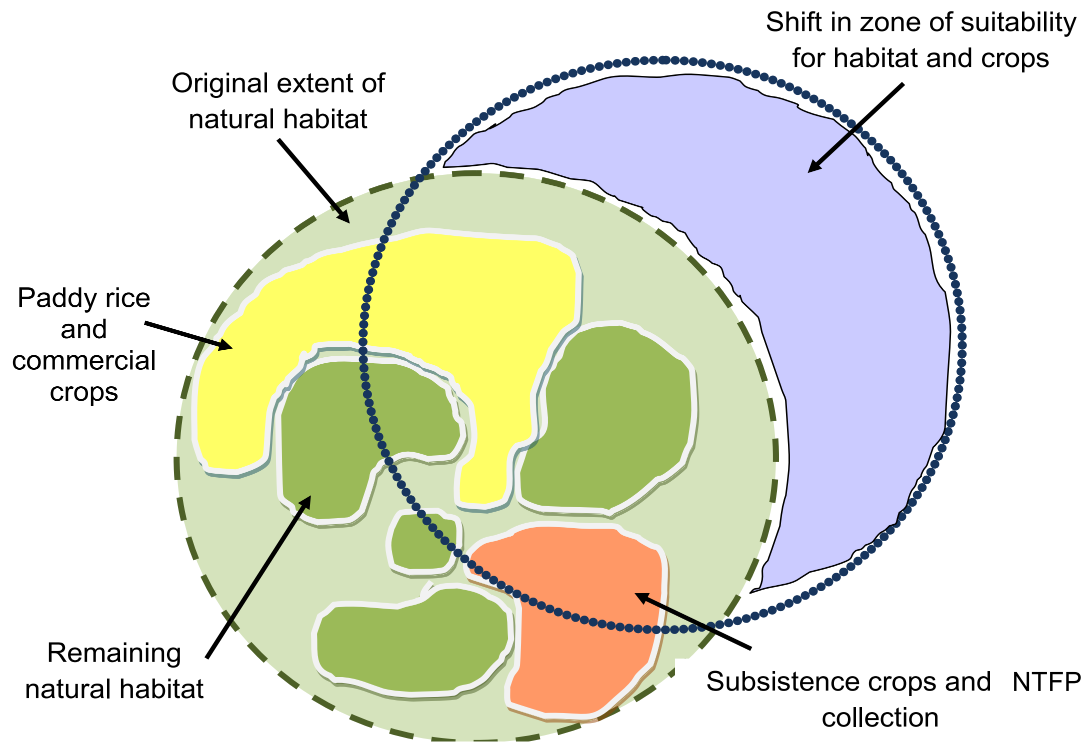
**Figure 3-2: Three shifts associated with climate change in the Lower Mekong Basin**



## Climate change shifts

***Climate change shifts are spatial or temporal changes in regular or extreme climate***. They include geographic shifts—which prompt changes in areas of suitability for specific habitats and/or crops; elevation shifts—affecting highly restricted habitats and species; and seasonal shifts—inducing a change in yields and cropping patterns. A good example of a temporal shift occurs in Chiang Saen, where under climate change the onset of wet season flow is projected to shift 15 days later. Shifts in regular climate may shift the zone of suitability for natural habitats and crops leading to changes in species composition in certain areas (Figure 3-3). Climate change shifts will involve species and spatial shifts in farming ecosystems.

**Figure 3-3: Geographic shift in climate leading to farming ecosystem shifts**




Extreme climate event shifts include changes in the intensity, frequency and location of those events. Precipitation-related events such as flash flooding are expected to shift to higher frequency. Macroevents such as saline intrusion in the delta are expected to become more intense due to increasing sea levels and storm surge. Shifts in extreme climate events may lead to permanent ecosystem changes.

## Ecosystem shifts

**Changes in climate will lead to ecological shifts as species and habitats adapt to the new climate regime. *An ecosystem shift occurs when the assemblage of species and habitats in a location changes to accommodate a new climate regime.*** Over time an ecosystem shift can give the appearance of gradual "movement" of plants and animals across the landscape as they follow the shifting climate, including movement to higher elevations or along corridors of remaining natural habitat. It can also involve the appearance of new assemblages some distance from their former location. Ecosystem shifts can be facilitated and managed by human intervention. They can also be prevented from occurring, e.g., by non-accommodating landuses or by the introduction of invasive exotic species.

### Farming systems shifts

Farming ecosystems rely on climatic and wider ecological services. **Climate and ecological shifts will lead to shifts in LMB farming ecosystems**. Crops and NTFPs which once flourished in an area are no longer suited to new conditions. Changes in climate mean that new crop species, cropping patterns, fishing activities, and gathering and foraging habits become necessary, and a new balance in system components and inputs needs to be established in any one location. It can also mean that certain types of farming will need to shift to entirely new locations where conditions and natural system ingredients have changed to suit.

Diminished or changing ecological provisioning may reduce availability and access to NTFPs and water. Weakening regulatory and habitat services may reduce pollination and pest control, reduce soil organic carbon content and reduce soil microfauna and flora. The culmination of these ecosystem shifts may mean that to maintain the character and productivity of a farming system in any given location will require more intensive inputs and a greater dependence on specialized, more resilient crops.

### 3.1.1.3 Climate change hotspots

***Climate change hotspots are areas of the basin projected to experience the greatest change in any one climate or hydrological parameter representing a threat or opportunity for existing farming and natural ecosystems.*** Identifying climate change hotspots enables the study to focus its analysis on areas likely to be most affected by future changes in climate. The threat or opportunity may be expressed through high absolute or relative percentage changes in annual or seasonal temperature, or precipitation, or by increases in flood duration caused by sea level rise and river floods. The study identified hotspot areas at various spatial scales including ecozone, catchment, province and protected areas. The spatial framework for the study is described in more detail in Section 3.1.2. The basis and methodology for identifying climate change hotspots is described in Section 3.3.

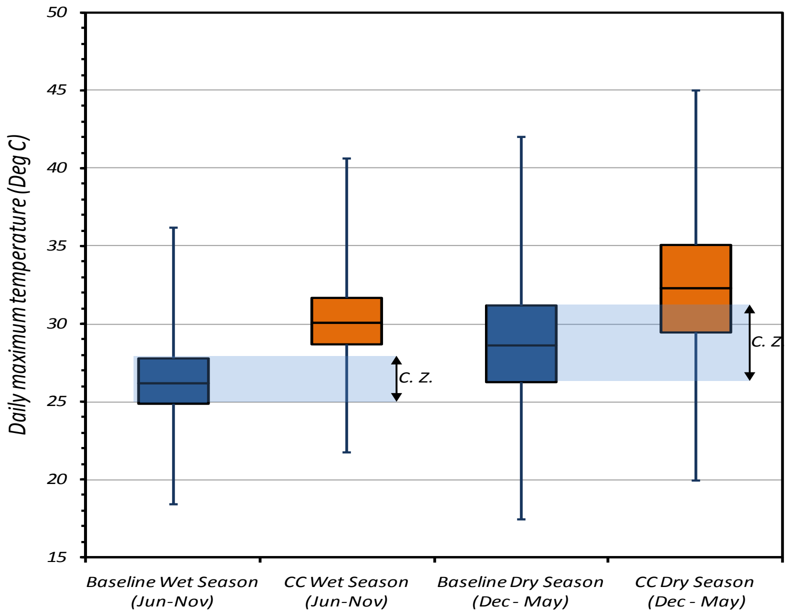
### 3.1.1.4 Comfort zones

***Comfort zones are where species and ecosystems experience the most suitable growing conditions in terms of the range and timing of temperature and rainfall.*** They are defined to include 50% of the baseline variability around the mean in temperature and rainfall for typical months, seasons and years.

All species have a range of climate in which they grow most comfortably. For agricultural crops usually that range is well understood—climate parameters have been studied in detail and published widely. For example, it has been shown that maize grows well in areas that have a total annual precipitation of between 500 and 5,000 mm and mean maximum temperature in the range of 26°C to 29°C. Outside this range the growth of the plant is constrained or inhibited entirely. For wild species and habitats, the comfort range is poorly researched and documented, even if known anecdotally by local communities and managers.

Comfort zone analysis requires information on the range of rainfall and temperature that was experienced during 50% of the historical baseline around the mean. For example, Figure 3-4 shows the wet season and dry season daily maximum temperature comfort zone for the mid-elevation dry broadleaf forest in Mondulkiri Province, Cambodia. In this area the ecosystem is adapted to and comfortable within a daily maximum temperature of between 25°C and 28°C during the wet season and 26°C and 31°C during the dry season. By 2050 the daily maximum temperature during the wet season will largely shift outside the baseline comfort zone—the dry season temperature will not shift as dramatically although the habitat will still become stressed. The comfort zone analysis enabled the study team to make rapid assessments on the relative impact of climate change on species and habitats.

**Figure 3-4: Maximum temperature comfort zone for mid-elevation dry broadleaf forest in Mondulkiri Province, Cambodia.** *Comfort zones are shown shaded in blue.*




### 3.1.1.5 Water availability index

Soil water availability is an important factor for agricultural production and ecosystem structure and function. By assessing the changes in water availability it is possible to make assessments on the timing of water stress conditions and the resultant impact on the productivity and health of flora species. The **water availability index** is an innovative modeling approach that the study developed to assess likely impacts of changes in temperature and precipitation on the levels of water available in the soil for vegetation growth. The water availability index is a measure of the water available in soil layers. The methodology for modeling the water availability index is described in Section 3.2.3.4.

### 3.1.1.6 Crop climate suitability and yield modeling

**The study applied two crop modeling tools to assess the impact of climate change on crops grown in the region**—climate suitability modeling and crop yield modeling. Knowing in advance which crops are suitable for the likely future climate conditions in an area will allow farmers to plan crop selection for optimal production.

**Climate suitability modeling assesses the temperature, precipitation, and drought characteristics of an area against known crop requirements to determine suitability for crop growth under existing and future climate.** Using this modeling method the study identified areas where changes in precipitation, temperature, and drought may cause changes in crop suitability. The basis and methodology for modeling climate suitability is provided in more detail in Section 3.2.

**Crop yield modeling assesses the total yield per unit area for each species based on existing soil and topographic conditions combined with temperature, precipitation, and water availability under existing and future climate**. For example, understanding the impact of climate change on rice yields in the LMB holds the key to assessing impact on livelihoods. The study undertook crop yield modeling for rainfed rice in hotspot areas to assess the likely impact of climate change on this dominant commercial and subsistence crop. The modeling assessed the likely impacts on the crop yield of rice in terms of changes in tonnes produced per spatial unit. The methodology for modeling crop yields is surmised in more detail in Section 3.2.

### 3.1.2 SPATIAL FRAMEWORK FOR THE STUDY

**The study took a spatial approach to the assessment**, working at a number of geographic levels from the overall basin down to a hotspot area focus (Figure 3-5). A common spatial framework was essential for integration of the different study components.

***Basin-wide analysis*** was focused on broad-scale themes such as climate threats and shifting crop suitability. The next spatial level down was ***ecozone*** defined by ICEM, building on prior WWF and national agricultural zone classification systems. Ecozones were chosen as the basic spatial unit for the region, rather than agricultural zones because of the need to emphasize the fundamental importance of natural systems and of biodiversity in local livelihoods and farming systems. Each ecozone represents the original ecosystems on which development is based. They recognize remaining natural assets as critical and in many areas the most important components of LMB farms.

For the socio-economic analysis, the ecozones were aggregated into five ***livelihood zones***, which reflect common livelihood strategies across multiple ecozones. The aggregation of livelihood zones is discussed in greater detail in Section 3.1.2.2. Ecozones and livelihood zones were used to identify areas with similar existing climate, ecosystems, and agricultural characteristics and potential, which allowed for upscaling of more localized vulnerability assessments and adaptation strategies. Three other spatial levels of analysis were utilized—***catchments***, especially for fisheries, ***provinces*** and, for the natural systems theme, ***clusters of protected areas***.

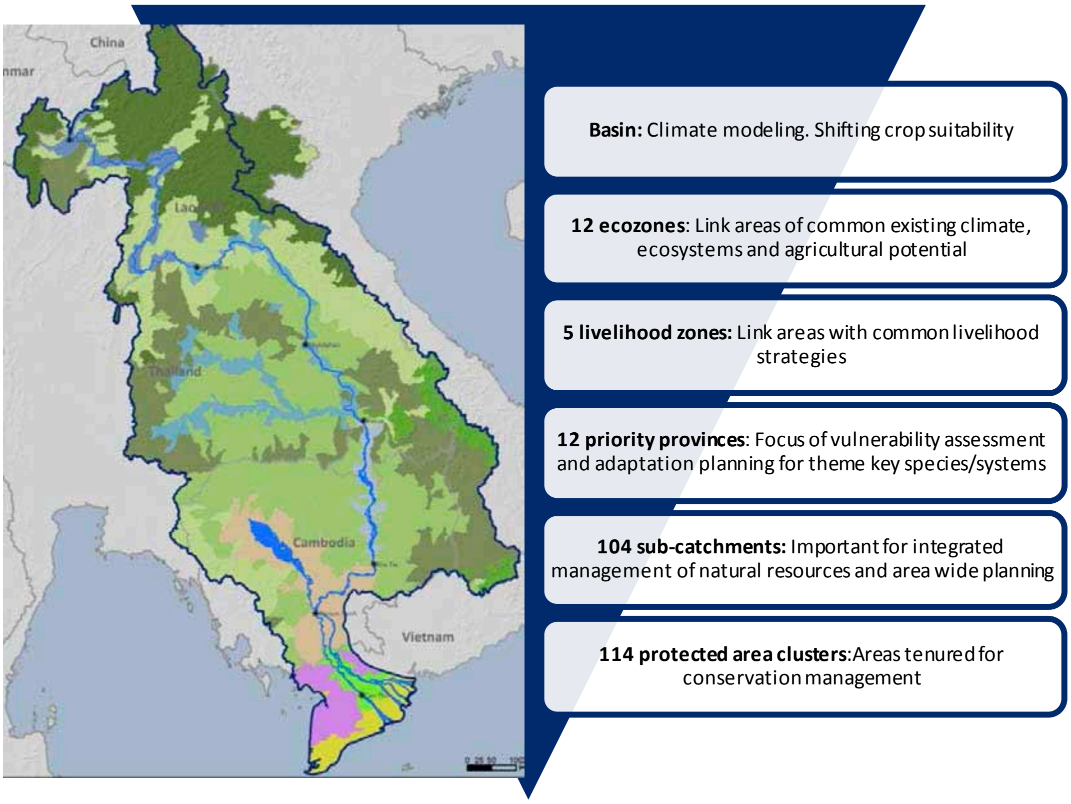
Species and ecosystems vulnerability assessments were undertaken at the province and protected area cluster level after identifying the priority provinces through a basin-wide assessment of the climate change threats.

#### 3.1.2.1 Ecozones

**The basin was divided into ecozones—areas of similar climate, ecosystems, and agricultural characteristics and potential.** The challenge in identifying the study's main spatial unit was to create zones with distinctive characteristics that facilitate an ecosystems approach to the assessment. Each ecozone represents a collection of similar biodiversity characteristics, significant habitats, and connectivity. These habitat classifications are not intended to capture localized bio-geographic variation in all cases; instead, they provide a unit of analysis for climate change vulnerability assessment by grouping areas that support similar assemblages of plants and animals due to analogous climatic and biophysical conditions. Moreover, identification of the specific vulnerabilities of a particular ecozone inherently generates common adaptive approaches and principles applicable to management, development, and conservation of biodiversity within each zone.

Ecozones reflect the original assemblages of plants and animals as the ecological context for rapidly evolving and expanding agricultural development. The study did not adopt conventional agricultural regions or zones as the foundation for analysis. These are based on agricultural potential and do not adequately reflect natural system linkages and contributions to LMB farming systems. Instead the study viewed agriculture in terms of farming ecosystems and analyzed them as part of wider ecological zones.

**Figure 3-5: Mekong Climate Study spatial scales**




The study reviewed the options and methods for defining basin-wide ecozones founded on strong information and consultation. The WWF Mekong Basin ecological zones (WWF 2002) were selected as the most useful initial basis for building the study ecozones—they were developed over several years from the late 1990s through extensive regional consultations. The WWF zones incorporate detailed data on elevation, historic land cover using WWF's terrestrial biomes, and floodplain wetlands.

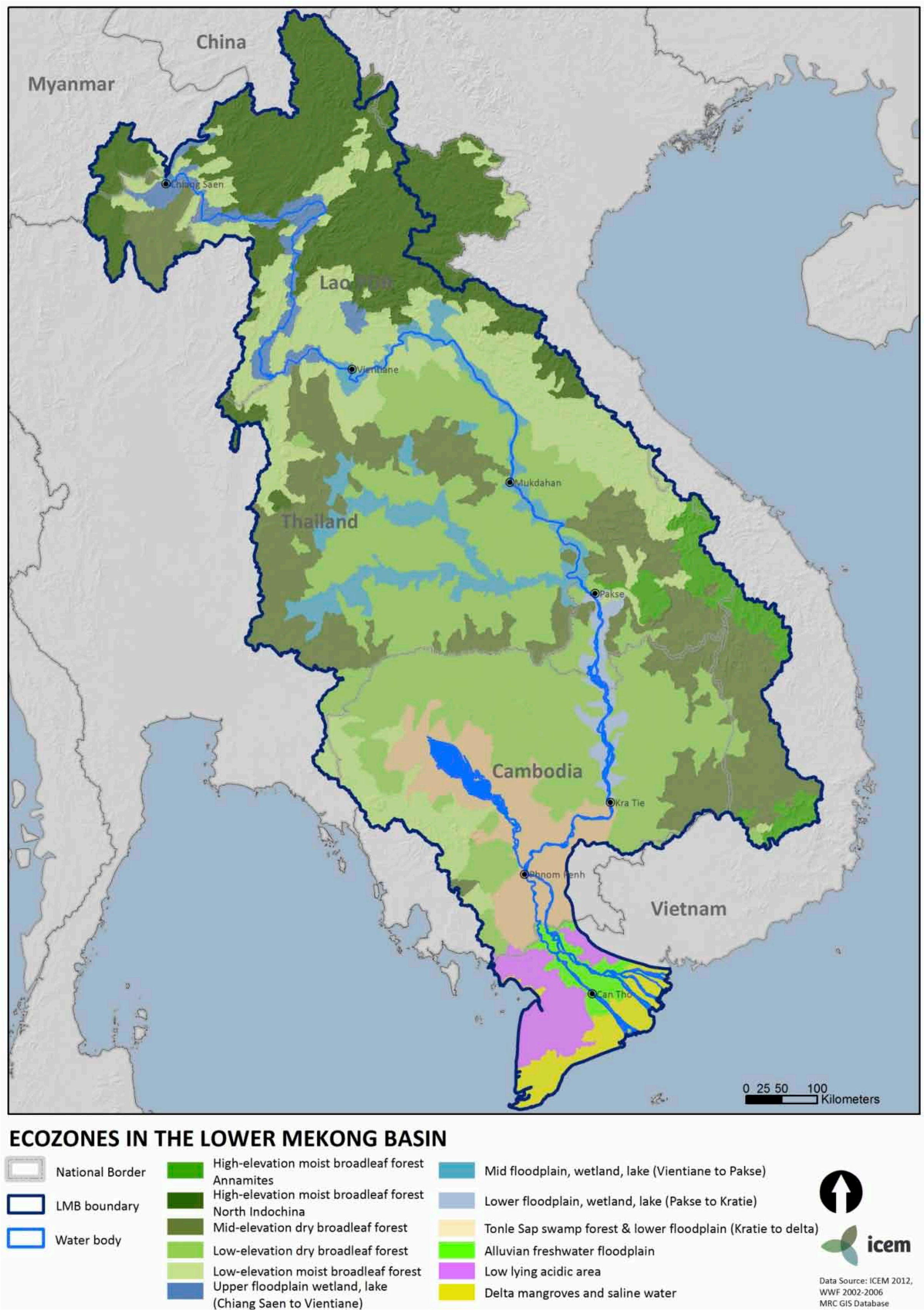
Refinements were needed to the WWF ecozones to reflect detailed field knowledge of the study team and take into account agricultural zones for each country based on various national interpretations of the Food and Agriculture Organization's (FAO's) methods for categorizing agricultural activity. The following changes were made to the WWF ecozones for purposes of this study:

- Area previously classified as "mangrove/delta" was split into three areas—"delta mangroves and coastal wetlands", "delta freshwater wetlands", and "delta acidic swamp forest";
- Area previously classified as "high-elevation broadleaf forest" was split into two areas—the Annamites region in the east of the LMB and the North Indochina area in the north of the LMB; and
- Areas classified as "Tonle Sap swamp forest" and "Lower floodplain, wetland (Kratie to delta)" were joined into one ecozone titled "Tonle Sap swamp forest and lower floodplain (Kratie to Delta)".

The final 12 ecozones in order of increasing elevation (Figure 3-6) are:

1. Delta mangroves and coastal wetlands
2. Delta freshwater wetlands
3. Delta acidic swamp forest
4. Tonle Sap swamp forest and lower floodplain (Kratie to Delta)
5. Lower floodplain, wetland, lake (Pakse to Kratie)
6. Low-elevation dry broadleaf forest
7. Mid-floodplain, wetland, lake (Vientiane to Pakse)
8. Mid-elevation dry broadleaf forest
9. Low-mid elevation moist broadleaf forest
10. Upper floodplain wetland, lake (Chiang Saen to Vientiane)
11. High-elevation moist broadleaf forest – North Indochina
12. High-elevation moist broadleaf forest – Annamites

**Figure 3-6: Ecozones of the Lower Mekong Basin**



### 3.1.2.2 Livelihood zones

For the purpose of assessing the climate change vulnerability and adaptation responses of socio-economic systems, it was necessary to aggregate the 12 ecozones into five livelihood zones: "*Forested uplands*", "*Intensively-used uplands*", "*Lowland plains and plateaus*", "*Floodplain*", and "*Delta*" (Figure 3-7). The original ecozone natural systems have been so modified and recent demographic and development forces so influential in shaping and homogenizing livelihoods in the basin that it was not possible to clearly define a distinctive farming system for each of the 12 ecozones.

The livelihood zones do provide an overview of common livelihood strategies for communities residing in similar ecozones. Table 2 summarizes the livelihood zone characteristics.

**Figure 3-7: Livelihood zones of the Lower Mekong Basin**

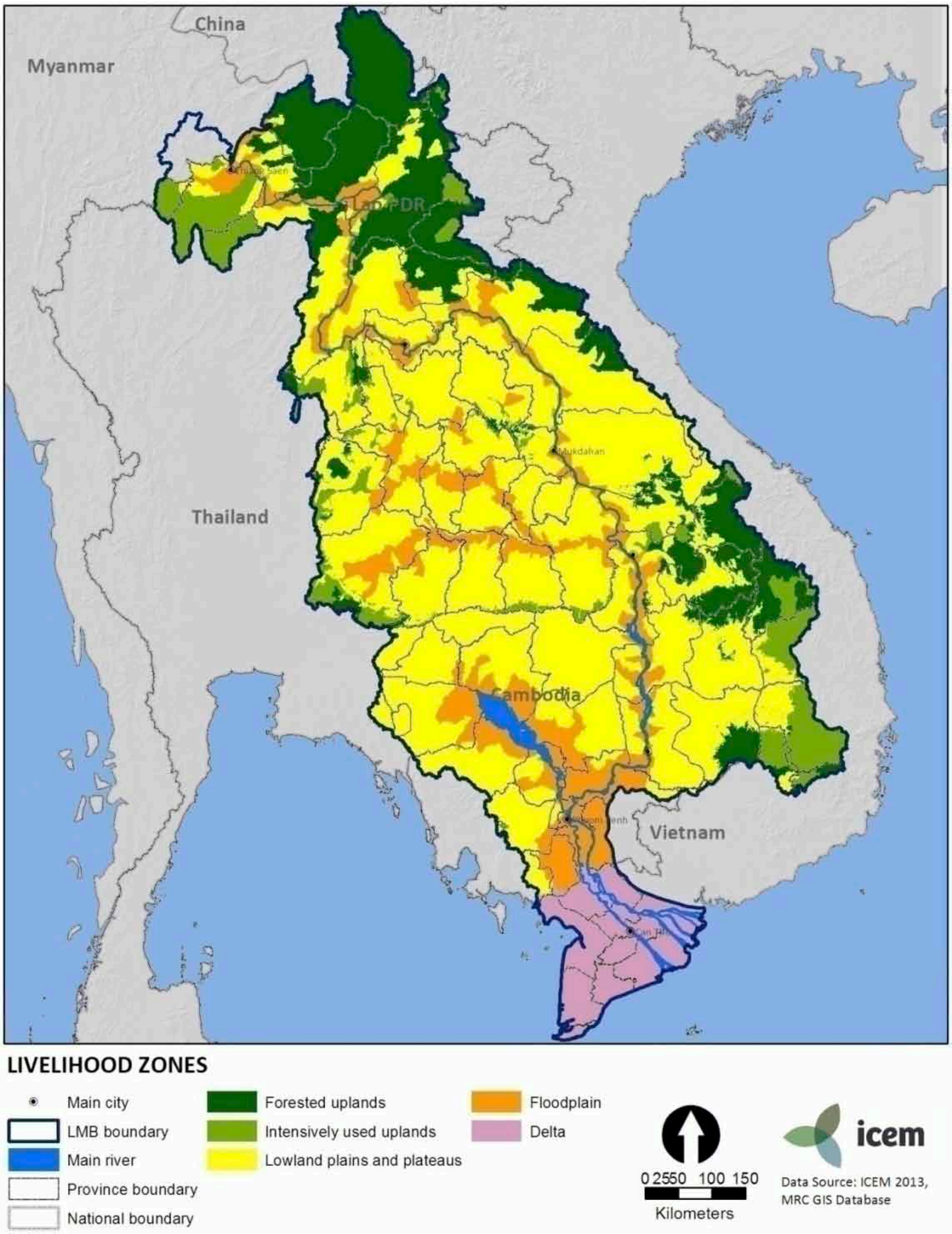


**Table 2: Summary description of livelihood zones**

| Livelihood zone | *Forested uplands* | *Intensively-used uplands* | *Lowland plains and plateaus* | *Floodplain* | *Delta* |
|---|---|---|---|---|---|
| Area (% of LMB) | 17% | 7% | 55% | 15% | 6% |
| Population (% of LMB) | 3% | 9% | 40% | 20% | 29% |
| Population Density (/$km^2$) | 16 | 114 | 71 | 130 | 506 |
| Poverty rate (% of population) | 39% | 21% | 30% | 24% | 12% |
| Main regions in each zone | N and SE Lao PDR, E Cambodia, Thai-Myanmar border | Vietnam Central Highlands, N Thailand | Central Lao PDR, E, N and W Cambodia, NE Thailand | Tonle Sap, SE Cambodia, Mekong River Floodplain, E Thailand | Mekong Delta |
| Main characteristics | Low population density, high poverty, poor health access and food security. Ethnic minority communities. Shifting cultivation. Low rates of electrification and other infrastructure. High level of subsistence agriculture. Diversity of livelihood activities. Exposed to flash floods and landslides. NTFPs a critical source of food and livelihoods. Upland rice instead of paddy rice. | Moderate to high population density. Intensive commercial agriculture. High rates of land degradation due to land-clearing on sloping land. Low rates of poverty among commercial farmers. High rates of poverty among minority groups living on more remote and marginal land. Exposed to flash floods and landslides. | Poverty varies from high (Cambodia) to low (Thailand) across countries. Rainfed agriculture. High food insecurity in some areas. Distance to markets may limit commercial opportunities. Poor soil fertility and low land productivity. Exposed to floods and droughts. | Relatively low food insecurity and poverty. Fishing a prominent subsistence and commercial activity. Exposed to seasonal floods. Closer proximity to markets and stronger access to healthcare and other infrastructure. High to medium population density. | Highly intensive commercial agriculture, but declining agricultural productivity. Relatively low levels of poverty and food insecurity, but present in some areas. Population density very high. Access to markets and services is high. Coastal fishing and aquaculture are prominent livelihood activities. |

*Note: Data includes both rural and urban populations. See Figure 7 of the USAID Mekong ARCC theme report - Vulnerability Assessment and Adaptation Planning for Socio-economics in the LMB for data sources. Areas include water-bodies. This table adapts a similar exercise in Johnson et al. (2009).*

### 3.1.2.3 Catchments

Potentially, the river sub-basin or catchment is an important level for integrated management of natural resources and area-wide planning. Thailand has advanced further than other LMB countries in river basin planning policies and institutional arrangements. Vietnam and Lao PDR has regulations to prepare river basin plans but those in place are narrowly based and implementation is limited. Climate change is an opportunity to reinforce the importance of the river basin or catchment level planning; area-wide adaptation plans for vulnerable river basins are advocated in this report. For that reason, the study adopted the 104 LMB catchments identified in the Mekong River Commission (MRC) database for climate change threat assessment and hotspot ranking as described further in Section 3.2.

Also, the fisheries theme group used catchments as an initial basis for gathering information on ecology of individual fish species and then upscaled to the ecozone level. Detailed literature on LMB fish species often stems from field surveys in defined catchments which can cut across the study ecozones—so the study had to build a database of species which could be identified with ecozones and of those that moved from one zone to another in their migrations and life cycle. More detail on the spatial approach taken by the fisheries group appears in the fisheries methods description in Section 3.4.5.

### 3.1.2.4 Provinces

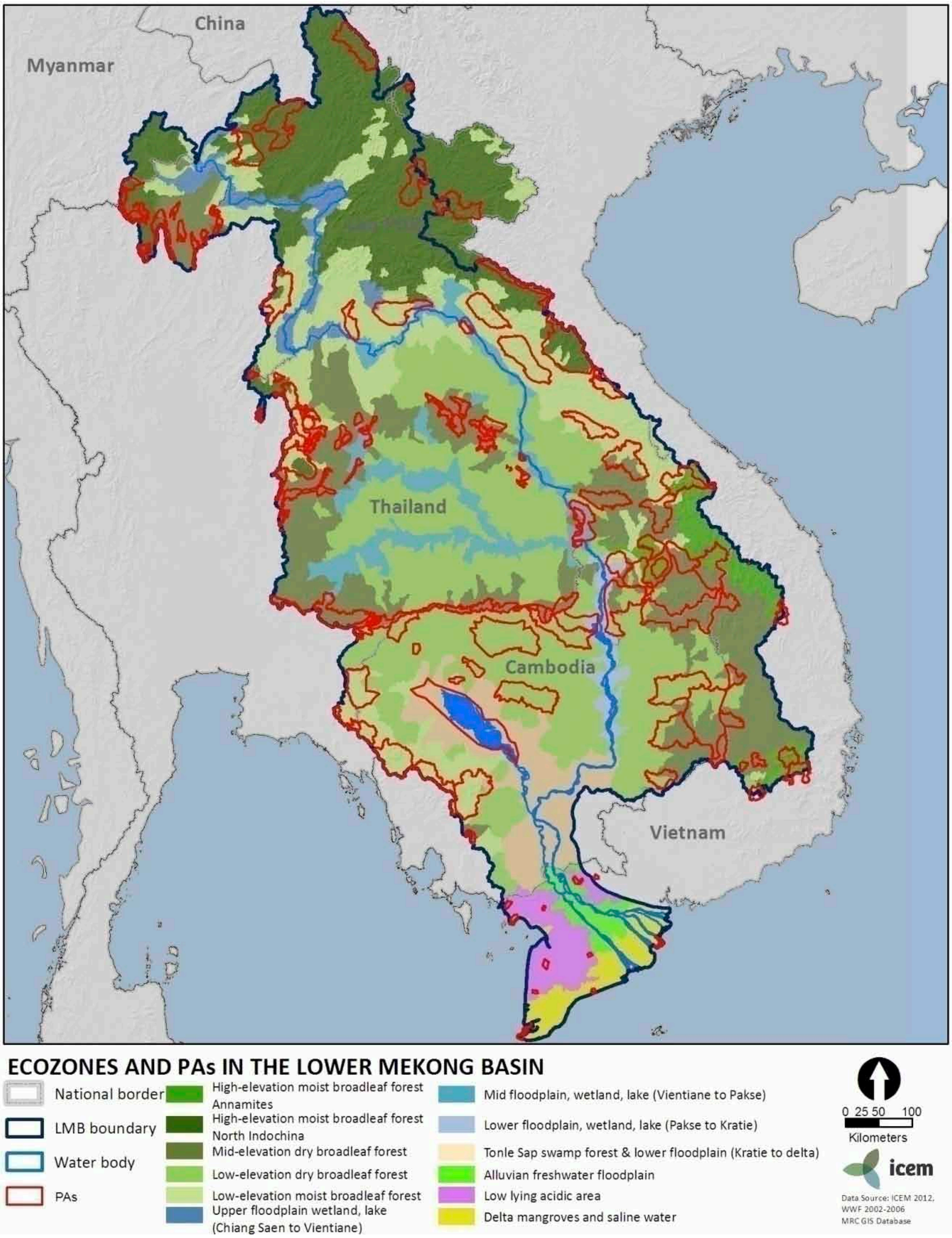
The only spatial unit of analysis used in the study that is not defined according to natural systems is the province. After ecozones, provinces comprise the main administrative and political unit used by the study for vulnerability assessment, for hotspot ranking, and for detailed adaptation planning. The two practical reasons for this provincial focus are (i) it is the main unit for gathering natural resource and socio-economic data in each LMB country and (ii) it is a key level of government for development planning, budgeting, and implementation and would likely be the most practical for adaptation planning and implementation.

The study found 88 provinces falling within the LMB. Those provinces that contained less than 100 ha of their total area in the LMB were eliminated. All provinces were assessed and ranked according to various parameters of climate change threat as described in the hotspot ranking description in Section 3.3. Each of the theme groups subjected the five highest ranked provinces to vulnerability assessment and another seven highly-ranked provinces to less detailed attention, consisting of 12 priority or hotspot provinces in all. The provincial assessments and adaptation planning were upscaled to the relevant ecozones and informed the basin-wide analysis.

### 3.1.2.5 Protected area clusters

There are more than 114 officially designated protected areas in the LMB (Figure 3-8) and more than 100 important wetland sites. Confronted with many threats and pressures, much of the region's biodiversity is retreating to these areas tenured for conservation management—they are areas of last resort for many species and habitats. The exact number of protected areas is uncertain because of the growing range being established at provincial and local level in all four countries—some within but many outside existing protected areas. They include fish conservation zones, community managed forests, biosphere reserves, and locally managed wetlands. The study included the 114 main areas in a climate change threat assessment and ranked them for various parameters (Section 5.4). That process led to the identification of five protected area clusters most threatened by climate change which were the focus of vulnerability assessments and adaptation planning.  The results of that habit or ecosystem wide assessment were then upscaled to ecozone level.

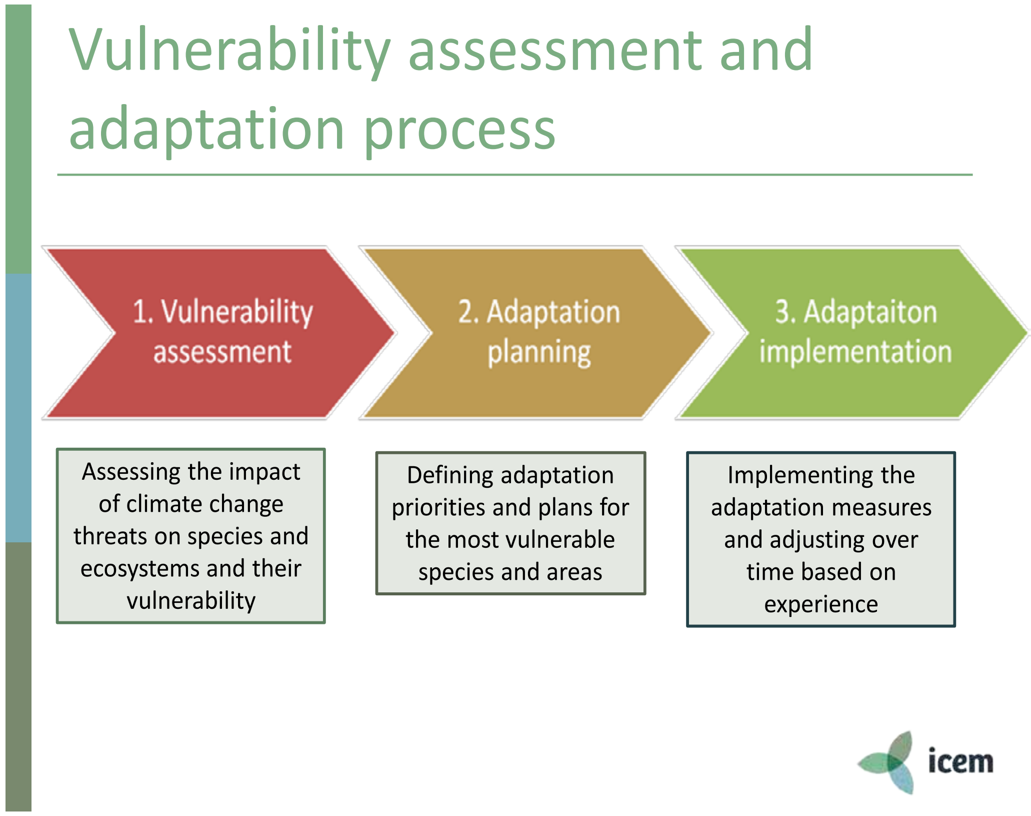
**Figure 3-8: Protected areas and ecozones in the Lower Mekong Basin**



### 3.1.3 THE CAM PROCESS

**The study applied the ICEM Climate Change Vulnerability Assessment and Adaptation (CAM) (ICEM 2012) methodology to the key systems and species identified for each theme in each of the priority provinces and protected area clusters.**

Figure 3-9: (a) Vulnerability assessment and adaptation process




Figures 3-9 (a) to (e) summarize the CAM process steps and concepts. It has three main phases—vulnerability assessment, adaptation planning, and then adaptation implementation (Figure 3-9 (a)). Those phases are intended to be integrated with government development planning and budgeting cycles. Example processes include socio-economic plans, sector development plans, area-wide plans, as well as project-specific planning and the environmental impact assessment process.

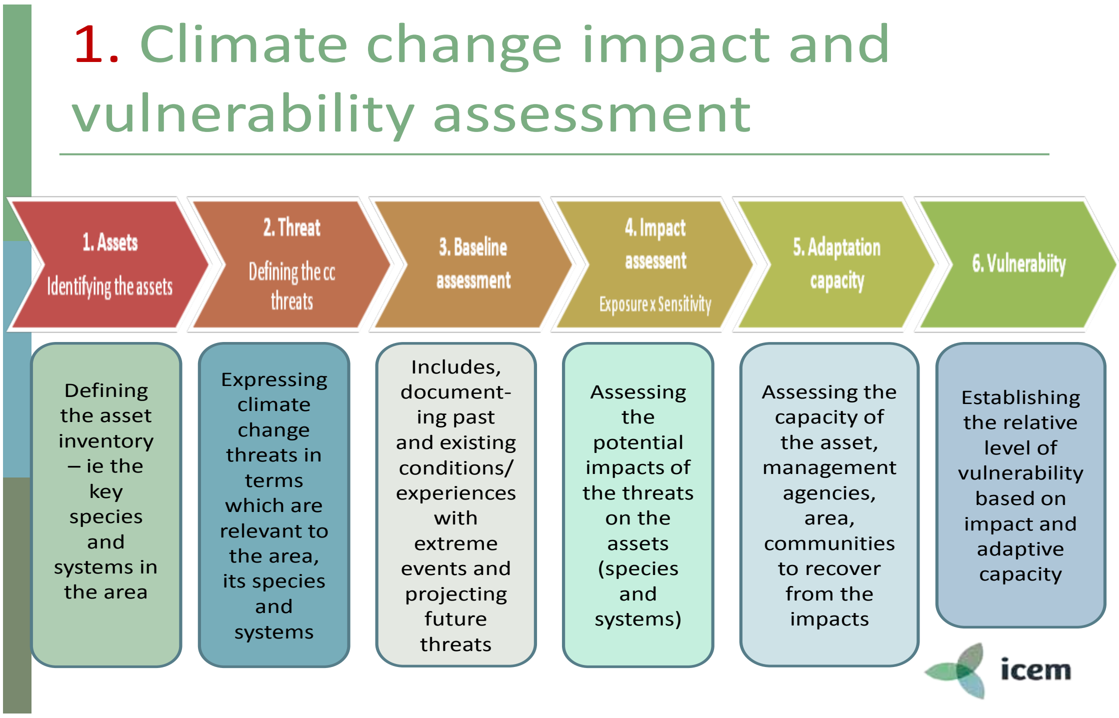
The ultimate objective is to build the CAM steps and tools into normal government, community, and private sector planning and review. Yet, while capacities and awareness are being raised, the adaptation process will need to be given high-profile billing and distinguished as a priority for sectors, communities, and areas.

The USAID Mekong ARCC study has gone only part way along the adaptation process—focusing on the first phase of identifying impacts and assessing vulnerability for large areas and key crops and wild species (Figure 3-9 (b)). The adaptation response partially followed the CAM process, emphasizing the identification of broad adaptation options and applying expert judgment and experience in defining priorities. The entire CAM process is described here to guide subsequent phases of the ARCC initiative, which will need to work through all assessment and adaptation phases in detail with affected communities and local governments.

#### 3.1.3.1 Impact and vulnerability assessment

The study theme groups applied the vulnerability assessment methodology to understand and document the causal linkages between climate change threats to different livelihood components in terms of their key species and, in the case of the natural systems group, species and ecosystems (Figure 3-9 (b)).

Figures 3-9 (b): Impact and vulnerability assessment process




The vulnerability assessment follows a recognized pattern of assessing the exposure and sensitivities to the climate change threats, and the likely impacts that may result. When combined with the adaptive capacity of the species or system, a ranking and analysis of their vulnerability can be made.

Figures 3-9 (a) to (e) are conceptual in nature. For their practical application, a precise step-wise process is defined and supported by a tool box which facilitates appropriate information inputs at each step. The operational vulnerability assessment and adaptation planning process involves six main components:

***Determining the scope***, by identifying the geographic and sector focus of the assessment and the species and systems (natural, social, economic, institutional, and built) which will be impacted.

Scoping tends to be an ongoing process which happens at various steps in assessment and planning. As the study progressed, the team defined the priority ecozones, catchments, provinces, and protected areas. It also defined the key species and systems for each theme. This process is described in later sections of the report.

***Determining the climate change threats*** through an analysis of past extreme events and trends and through climate modeling and downscaling of future climate and hydrology against various scenarios. The definition of projected climate change threats is part of the baseline—it needs to be fine-tuned to the specific sensitivities of the species and areas under focus in the form of *threat profiles*.

***Conducting a baseline assessment*** to describe the past and existing situation, trends and drivers across each of the identified systems, and projecting the changes to these systems which will occur irrespective of climate change. The baseline involved the review of scientific, socio-economic and development literature, existing databases, consultation with other experts, and team expert judgment. The theme baseline assessments are provided in the separate theme volumes prepared for this study and include:

- Identification of key species/systems,
- Description of key species/systems,
- A species/systems database including climate tolerances,
- Description of impacts of past extreme events,
- Identification of linkages between sectors,
- Ecozone profiles covering key species/systems, and
- Priority province profiles covering key species/systems.

***Conducting the impact assessment***: For each of the target species and systems, the exposure, sensitivity, impact, and adaptive capacity were defined using the baseline and climate threat modeling results and matrix support tools developed by ICEM. The theme vulnerability assessments are summarized in the separate theme volumes to this report.

The CAM method outlines four important factors in assessing vulnerability of the target species and systems to the defined climate change threats: exposure, sensitivity, impact, and adaptive capacity and provides a set of tools to facilitate assessments at each stage (Figure 3-9 (c)). **Exposure** is the degree of climate stress on a particular system or species; it is influenced by long-term changes in climate conditions, and by changes in climate variability, including the magnitude and frequency of extreme events. **Sensitivity** is the degree to which a species or system will be affected by, or responsive to climate change exposure. The potential **impact** (or level of risk) is a function of the level of **exposure** to climate change-induced threats, and the **sensitivity** of the target assets or system to that exposure. **Adaptive capacity** is understood in terms of the ability to prepare for a future threat and in the process increase resilience and the ability to recover from the impact. Determinants of adaptive capacity include:

***Natural systems***

- Species diversity and integrity
- Species and habitat tolerance levels
- Availability of alternative habitat
- Ability to regenerate or spatially shift
- For individual species: dispersal range and life strategy

***Infrastructure***

- Availability of physical resources (e.g., materials and equipment)
- Backup systems (e.g., a plan B)

***Social factors***

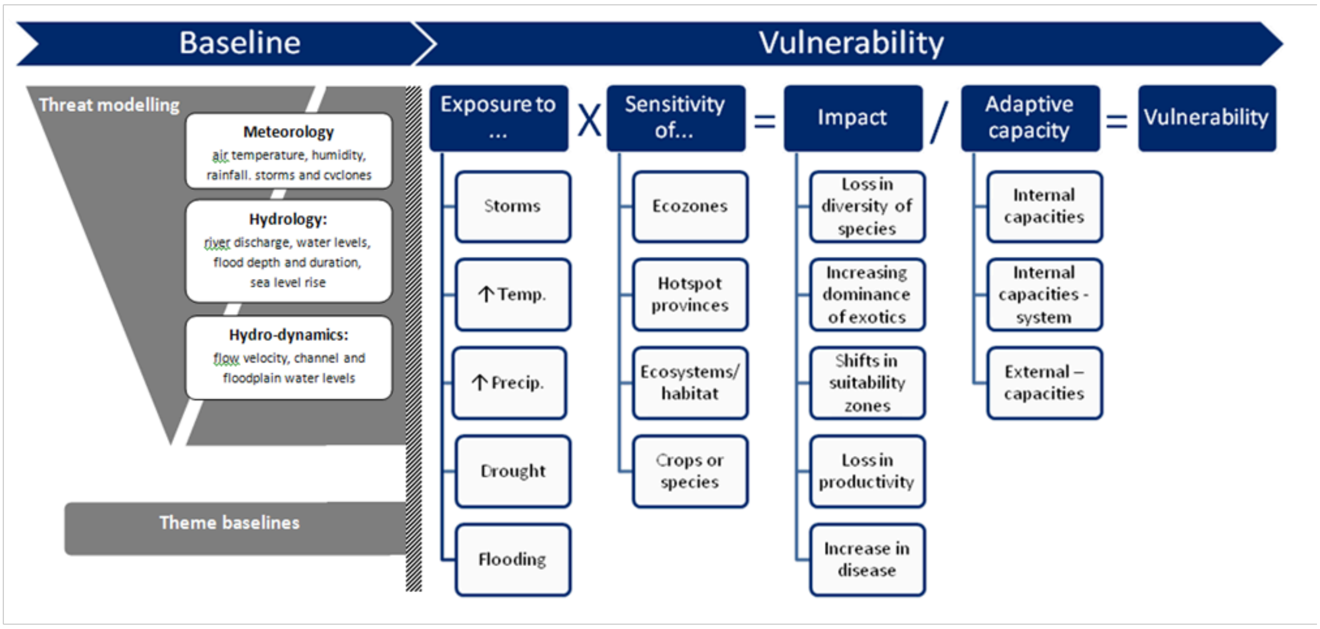
- Social networks
- Insurance and financial resources
- Access to external services (medical, finance, markets, disaster response, etc.)
- Access to alternative products and services

***Crosscutting factors***

- The range of available adaptation technologies, planning, and management tools
- Availability and distribution of financial resources
- Availability of relevant skills and knowledge

- Management, maintenance, and response systems including policies, structures, technical staff, and budgets
- Political will and policy commitment

Figure 3-9 (c). Parameters and issues considered in the baseline and vulnerability assessment process




When impact and adaptation capacity are considered, a measure of relative vulnerability can be defined.

The CAM method can use numerical scoring for exposure, sensitivity, impact, and adaptive capacity leading to a comparative score for vulnerability, or it can use qualitative terms from very low to very high with the aid of assessment tools which come with the method. The study team tested both approaches and one other ICEM vulnerability assessment method designed specifically for wild species which uses a numerical scoring system. With the exception of the natural systems group, all theme groups decided on the CAM method using qualitative terms. They found this provided a more transparent and flexible way to describe impacts and vulnerabilities in situations where the assessment was driven by expert judgment. For NTFPs and CWRs, the natural systems group decided to use the special purpose method as described later in section 3.4.3.

Tables 3 (a) and (b) show the scoring matrices used in the study to assess impact and vulnerability.

**Table 3: (a): Determining impact and (b): Determining vulnerability**

| | | *Exposure of system to climate threat* | | | | |
|---|---|---|---|---|---|---|
| *Sensitivity of system to climate threat* | | *Very Low* | *Low* | *Medium* | *High* | *Very High* |
| | *Very High* | *Medium* | *Medium* | *High* | *Very High* | *Very High* |
| | *High* | *Low* | *Medium* | *Medium* | *High* | *Very High* |
| | *Medium* | *Low* | *Medium* | *Medium* | *High* | *Very High* |
| | *Low* | *Low* | *Low* | *Medium* | *Medium* | *High* |
| | *Very Low* | *Very Low* | *Low* | *Low* | *Medium* | *High* |

| | | *Impact* | | | | |
|---|---|---|---|---|---|---|
| *Adaptive Capacity* | | *Very Low Inconvenience (days)* | *Low Short disruption to system function (weeks)* | *Medium Medium term disruption to system function (months)* | *High Long term damage to system property or function (years)* | *Very High Loss of life, livelihood or system integrity* |
| | *Very Low Very limited institutional capacity and no access to technical or financial resources* | *Medium* | *Medium* | *High* | *Very High* | *Very High* |
| | *Low Limited institutional capacity and limited access to technical and financial resources* | *Low* | *Medium* | *Medium* | *High* | *Very High* |
| | *Medium Growing institutional capacity and access to technical or financial resources* | *Low* | *Medium* | *Medium* | *High* | *Very High* |
| | *High Sound institutional capacity and good access to technical and financial resources* | *Low* | *Low* | *Medium* | *Medium* | *High* |
| | *Very High Exceptional institutional capacity and abundant access to technical and financial resources* | *Very Low* | *Low* | *Low* | *Medium* | *High* |

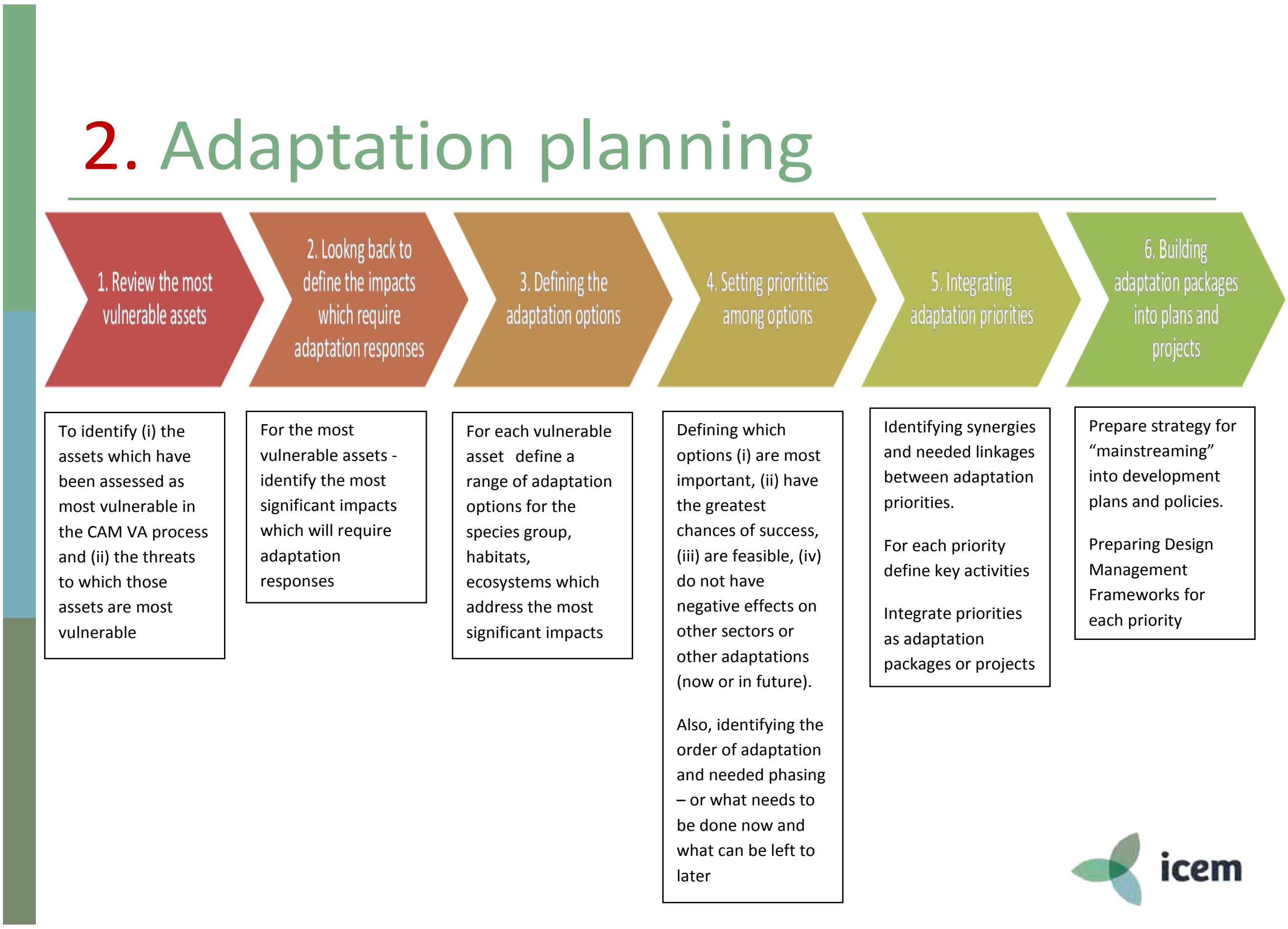
### 3.1.3.2 Adaptation planning

***Defining adaptation responses:*** this step in adaptation planning includes developing a range of **options** and then determining **priorities** (Figure 3-9 (d))—with limited resources it is not possible or necessary to do everything at once; choices need to be made on what is feasible now and what can be left to later planning cycles.

The rapid adaptation planning approach applied by the study is described in more detail in the theme methods sections to follow. It involves:

- **Identifying the most vulnerable species and systems and then defining the impacts which require adaptation response.** The most vulnerable assets are identified through application of the CAM vulnerability assessment method.
- **Defining the adaptation options for the most significant impacts**. The study drew from international and regional experience of what has worked for past extremes to prepare adaptation options to address assessed impacts of projected threats to vulnerable species and systems.
- **Guidance for adaptation planning.** The study identified priorities and phasing for adaptation options taking into account the need to: (i) address the adaptation deficit, (ii) build on existing effort and when necessary take new adaptation initiatives, and (iii) address the system shifts which are anticipated with climate change. The options were identified as short, medium, or long-term priorities. For each adaptation option the study also (i) assessed opportunities for *integration and synergies*, i.e., opportunities for linkages and synergies in adaptation with other themes; (ii) conducted *adaptation impact assessments*—identifying potential for negative impact on other themes, sectors, or areas; and (iii) defined *geographic scope*—identifying geographic scope of adaptation, e.g., local/farm level, provincial, national, ecozone/livelihood zone to basin-wide.
- **Upscale to ecozone or livelihood zone level.** Adaptation options at the local, farm, and provincial level were upscaled to similar ecosystems or livelihood areas through the ecozone and livelihood zones.

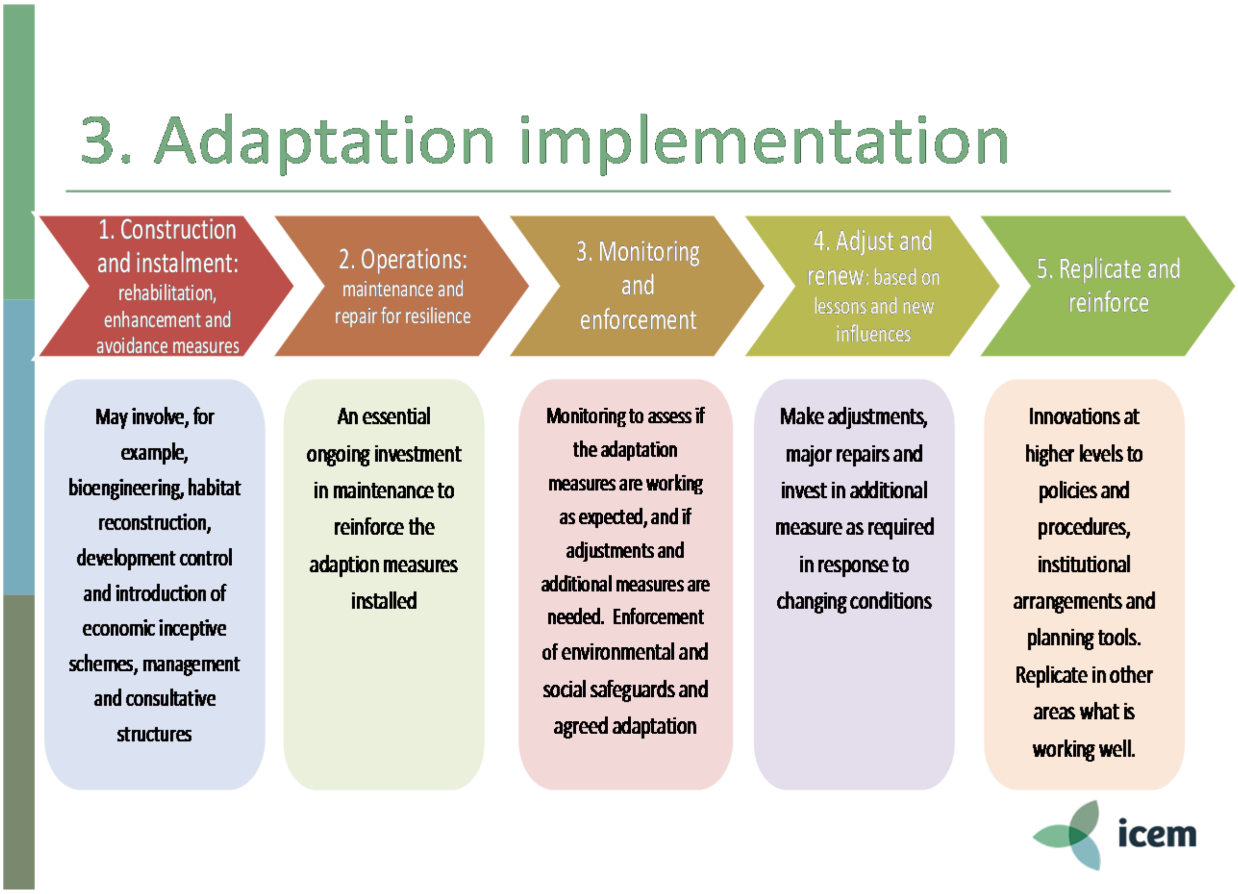
Figure 3-9 (d): Adaptation planning process




### 3.1.3.3 Adaptation implementation and feedback

***Providing feedback on adaptation implementation***: Monitoring implementation and making adjustments and additions based on experience and new information is critical to taking a phased and systematic approach to adaptation (Figure 3-9 (e)). That learning process will be a key part of USAID Mekong ARCC subsequent phases.

Figure 3-9 (e): Adaptation implementation process




## 3.2 CLIMATE AND HYDROLOGICAL ANALYSIS METHODS

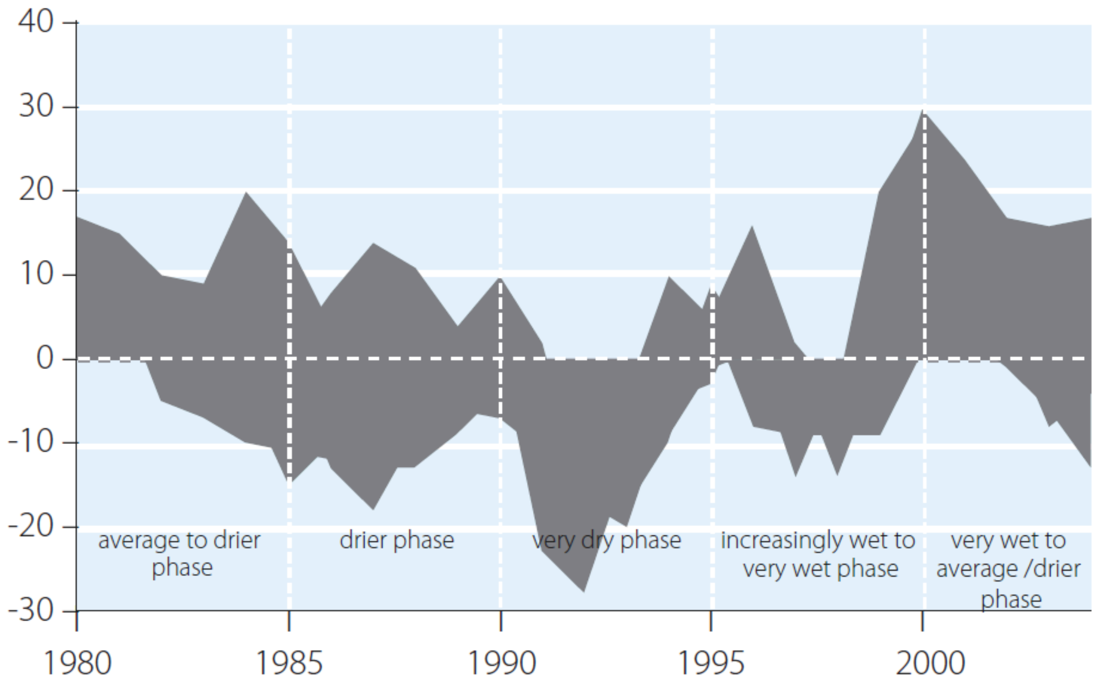
### 3.2.1 ASSESSMENT TIME SLICES

Time slices represent a critical and first decision point in climate change vulnerability and adaptation assessments because they have a strong influence on both: the magnitude of climate change impact as well as the ability for scientific assessments to lock into the timing and phasing of sector, government, and community planning cycles. Setting time slices too near to the present can mean the climate change signal cannot be discerned above normal climate variability, while time slices set for the distant future remain detached from shorter-term planning cycles (Orlove 2010). In response, the study uses a number of time slices to draw conclusions on the directionality and magnitude of climate change and then scale back to entrench these in development planning.

#### 3.2.1.1 Baseline time slice

**The baseline time slice has been selected to accommodate the significant spatial and temporal variability in the LMB hydroclimate**. One of the major difficulties in climate change assessments in the Mekong is reconciling the complex inter-decadal trends in climate and rainfall. Because of the complexity in the Mekong hydroclimate (c.f. Section 2) the Mekong rainfall regime undergoes decadal patterns of wet and dry spells influenced by the strength of the monsoon, occurrence of cyclone activity, and ENSO variations (Figure 3-10). Previous studies have found that mean annual rainfall between decades can vary by as much as +/-30% (Johnston et al. 2009, MRC 2011, Rasanen et al. 2012, and Rasanen et al. 2013).

**Figure 3-10: Decadal variability in Mekong rainfall:** *Percentage variance of the range in annual rainfall values compared to the long-term historical mean.* (Source: MRC 2010)




**The selection of the baseline period affects the magnitude of relative climate change because it provides the historic levels against which future climate change is assessed** and determines what kind of climate conditions (average, wet, dry) are incorporated as part of that baseline. Short baselines could result in a drier or wetter average baseline rainfall which consequently could over or underestimate future impacts projected by climate change modeling. At the same time, longer baselines reduce the coverage of monitoring stations which have the required time series duration in observational data, resulting in a poorer spatial distribution of input data and less confidence in spatial interpolation between monitoring stations.

**The study utilizes a 25 year baseline period of 1980–2005 for all analysis**. The period ensures that average (early 1980s), wet (1996–2005) and dry phases (1985–1995) were captured in baseline trends (Figure 3-10). The period also allows for the use of 166 temperature and rainfall monitoring stations within the LMB providing an average coverage of one station per 7,400 km² (Table 4)[6].

**Table 4: Spatial distribution of meteorological monitoring stations used in the study**

| LMB Country* | No. Precipitation stations | No. Temperature Stations | Total | Station Density (km²/station) |
|---|---|---|---|---|
| Cambodia | 6 | 6 | 12 | 13,090 |
| Lao PDR | 16 | 4 | 29 | 10,388 |
| Thailand | 98 | 12 | 110 | 1,714 |
| Vietnam | 7 | 8 | 15 | 4,481 |
| ***Total*** | ***127*** | ***30*** | ***166*** | ***7,418*** |

** Note: This table only shows stations within the Lower Mekong Basin, a number of stations in the Upper Mekong Basin and the surrounding catchments were also used in the modeling but have not been included in calculating densities.*

#### 3.2.1.2 Future time slices

The original aim of the Mekong Climate Study was to provide assessment of impacts associated with a global mean surface temperature rise of 2°C and the expected scale of impacts for time slices at 2030 and 2050.

**2°C has long been considered as a tipping point of the global climate system** above which catastrophic impacts such as destabilization of the Indian monsoon, collapse of the Greenland and Antarctic ice sheets, and disruption to the El Nino Southern Oscillation (ENSO) and Atlantic Thermohaline Circulation, amongst others, become realistic possibilities (Schellnhuber 2012, Lenton et al. 2008)[7]. Consequently, global negotiations and discussions on Green House Gas (GHG) emissions have centered on this target.

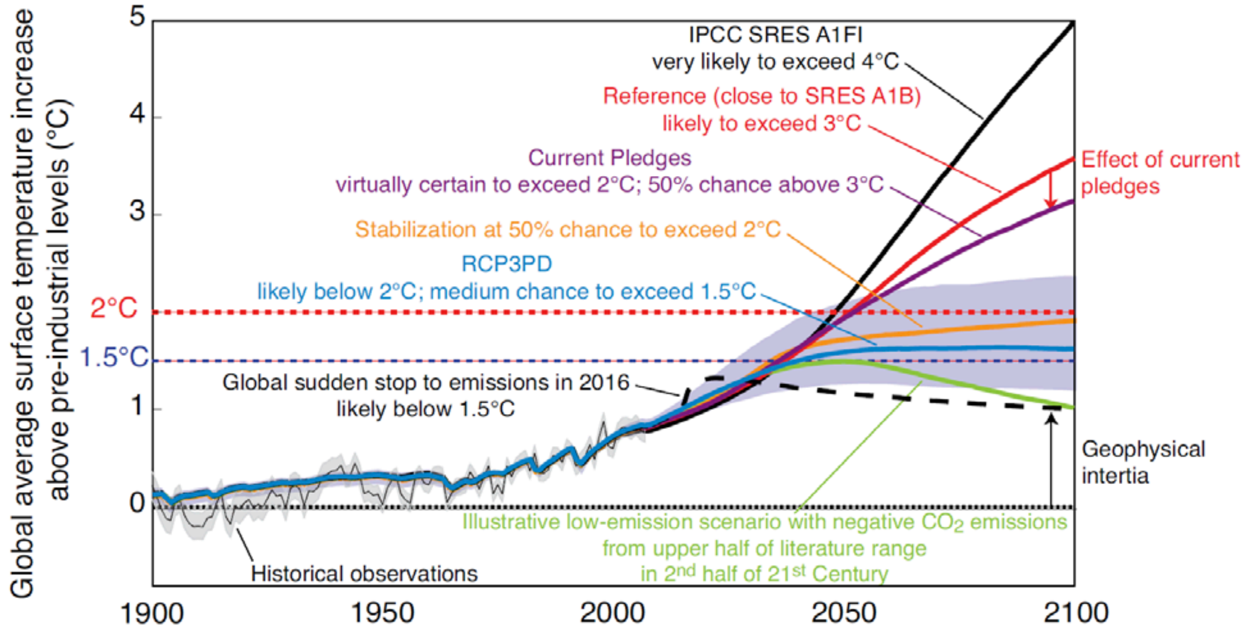
**While 2°C remains the target for climate negotiations and agreements, the likelihood of keeping temperature increases below this threshold is increasingly becoming implausible**. In order to do so, global emissions for all GHGs would need to peak by 2015–2020, and then reduce at a rate of at least 5% per year thereafter (WBGU 2009). This could only be achieved if developed nations reduce their emissions contributions by 25% to 40% in the next decade, and then global emissions would need to be halved by 2050 (WBGU 2009). The latest round of emissions pledges, which were agreed to in Cancun, fall well short of these targets and therefore will not maintain increases in global temperatures at or below 2°C. These existing pledges would more likely result in warming of more than 3°C by the end of the century, with a 20% chance of exceeding 4°C. If these pledges are not met, then there is a 40% chance that global temperature increases will exceed 4°C by the end of the 21st century (Figure 3-11, World Bank 2012).

[6] The baseline period is restricted to a 25 year period due to data availability and quality issues. More detail on observation data is provided in Annex I.

[7] These processes are provided as examples of the importance given to the 2°C time slice; the study is not claiming to have analyzed the potential impacts of these potential catastrophic climate failures.

**USAID Mekong ARCC, therefore, needs to move beyond 2°C** and consider more drastic warming signals of 4°C+ by the end of the century. There is broad consensus amongst the international climate science community for this position. This has also become apparent for the Mekong Basin. The study's model findings show a projected average annual change in temperature for the Mekong Basin exceeding 3°C by 2050 (and up to nearly 5°C in some small upland areas). As the 4°C+ advocates argue, we need to understand the implications of these higher temperature increases to inform our adaptation planning—not limit the adaptation assessments to a target which is now considered unrealistic.

**Figure 3-11: Projected changes in global mean surface temperatures using high (A1F1), moderate (A1B), and low (RCP3-PD) emissions scenarios** *(Source: World Bank 2012)*




**The Mekong Climate Study assessments focus on a 25 year time slice from 2045 to 2069 (referred to as "2050") as a suitably distant and sufficiently clear signal in both the directionality and scale of change in the Mekong hydroclimate system**. The expected scale of impacts by 2030 and a 2°C time slice is assessed by scaling back the 2050 projections. The team did not run separate simulations for 2030 and 2°C time slices for all hydroclimate parameters assessed under the Mekong Climate Study, but instead took the following approach:

(i) Analysis of the full daily temperature time series (1980–2100) for a limited number of stations in the LMB to assess the long-term trend of climate change in the basin and the timing of the 2°C anomaly;

(ii) Comparison of the trends identified to global trends taken from existing Intergovernmental Panel on Climate Change (IPCC) results;

(iii) Detailed quantification and assessment of 2050 changes to more than 30 hydroclimate parameters on their impacts on Mekong rural livelihoods system; and

(iv) Expert judgment/analysis of long-term trends in daily temperature to scale back findings on impacts to 2030 and 2°C time slices.

**All discussion in this report on changes in climate refers to the change in parameters between two 25 year periods: (i) baseline 1980–2005, and (ii) future climate, 2045–2069**—unless otherwise stated.

### 3.2.2 CLIMATE CHANGE THREATS

Using the 2050 time slice, the Mekong Climate Study assessed changes in a number of hydroclimate variables, including: temperature, rainfall, runoff, erosion, stream flow, flood depth/duration, saline intrusion, soil moisture, and tropical storm events. In total, the study team drew upon more than 30 parameters which were identified as being relevant to the seven thematic areas covered by USAID Mekong ARCC. The purpose of using this large selection of climate parameters is to where possible link and quantify the changes in the hydroclimate with specific impacts on the system or sector being assessed.

**Climate Variability**: the variation in hydroclimate parameters at time scales of seasons, years, or a few decades.

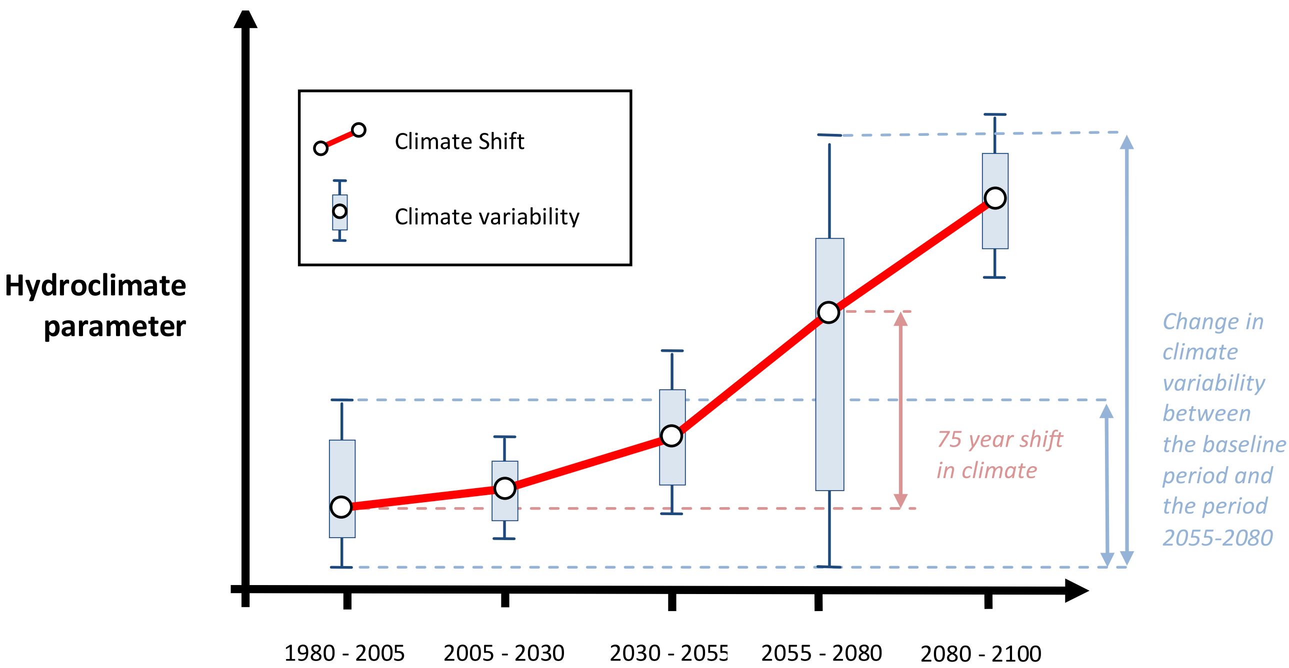
**Climate shifts**: variation in hydroclimate parameters at much longer time scales of more than several decades.

Future projections for changes in these variables are expressed in terms of *climate shifts* and *climate variability*. This study utilizes both concepts in quantifying the projections of the future Mekong hydroclimate based on the length of the time scale in relation to the length of the baseline period (1980–2005) (Figure 3-12):

- *Within 25 year periods*, the study assesses the variability and properties of hydroclimate parameters.
- *Between 25 year periods*, the study quantifies the longer-term trend or signal in these hydroclimate parameters.

These shifts and variations in hydroclimate parameters result in the quantification of how the hyroclimatic characteristics of the LMB will change in response to global climate change projections, which are then analyzed using spatial and statistical techniques.

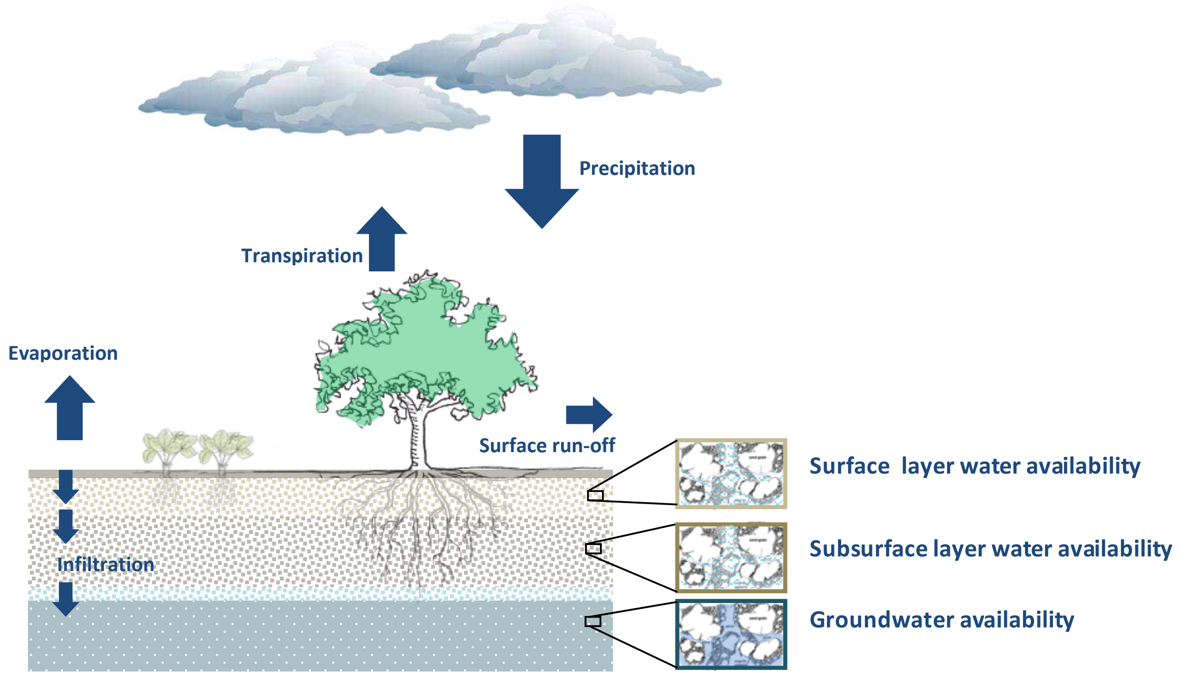
**Figure 3-12: Quantifying changes in hydroclimate variables:** *The study assesses long-term signals of shift over multiple decades, as well as the variability between years and seasons within 25 year periods (Diagram is illustrative only)*



**Robust causal linkages are then needed to establish impact pathways between these changes in hydroclimate and aspects of the natural and agricultural systems underlying Mekong rural communities**. This was achieved by identifying *processes* and *functions* of the agro-ecological system that are critical to the integrity and productivity of the system and linking them to hydroclimate parameters. For example:

- **Hydrobiological seasons and fish migration**: Fisheries specialists in the study team were able to link changes in the timing and duration of the transition season from dry to flood with effects on migration of white fish from the Mekong floodplains to the upriver spawning grounds.
- **Soil water availability and vegetation growth:** The soil water availability is a measure of the water available in soil layers and is directly relevant to plant growth. Moisture in the surface soil layer, to a depth of 0.5 m, is available to annual crops and vegetables which have shorter root systems, while the deeper subsurface soil moisture is available to trees with deeper root systems. Climate change may cause proportional changes in the availability of water within the two layers which may cause future stress or suitable growth conditions. To model the soil water availability index, a set of empirical equations was built into the Integrated Water Resources Management (IWRM) model to calculate the water balance for each cell at each time step. The water balance was calculated as a culmination of the precipitation, evaporation, surface runoff, and water available in the surface soil layer, subsurface soil layer, and groundwater (Figure 3-13).
- **Water availability and crop production**: Agriculture specialists linked changes in rainfall, soil moisture, and evaporation rates with productivity of annual crop systems. The study focus is on habitats and species so an agricultural definition of drought was adopted; i.e., drought occurs when there is insufficient water to meet the needs of plant species at any given time and is commonly defined as when precipitation in a given month is less than 50% of the evapotranspiration (Sys et al. 1993). This definition of drought was incorporated into the IWRM model and GIS analysis was used to assess the changes in drought across the basin.
- **Extreme temperatures and spread of disease amongst livestock**: Livestock specialists linked changes in magnitude and frequency of extreme temperatures with disease in various livestock species.
- **Seasonal surface water ponding and wetland habitat integrity**: Natural systems specialists were able to link changes in dry season surface ponding to extent and integrity of habitat of wetland systems.

**Figure 3-13: Components of the soil water availability index**



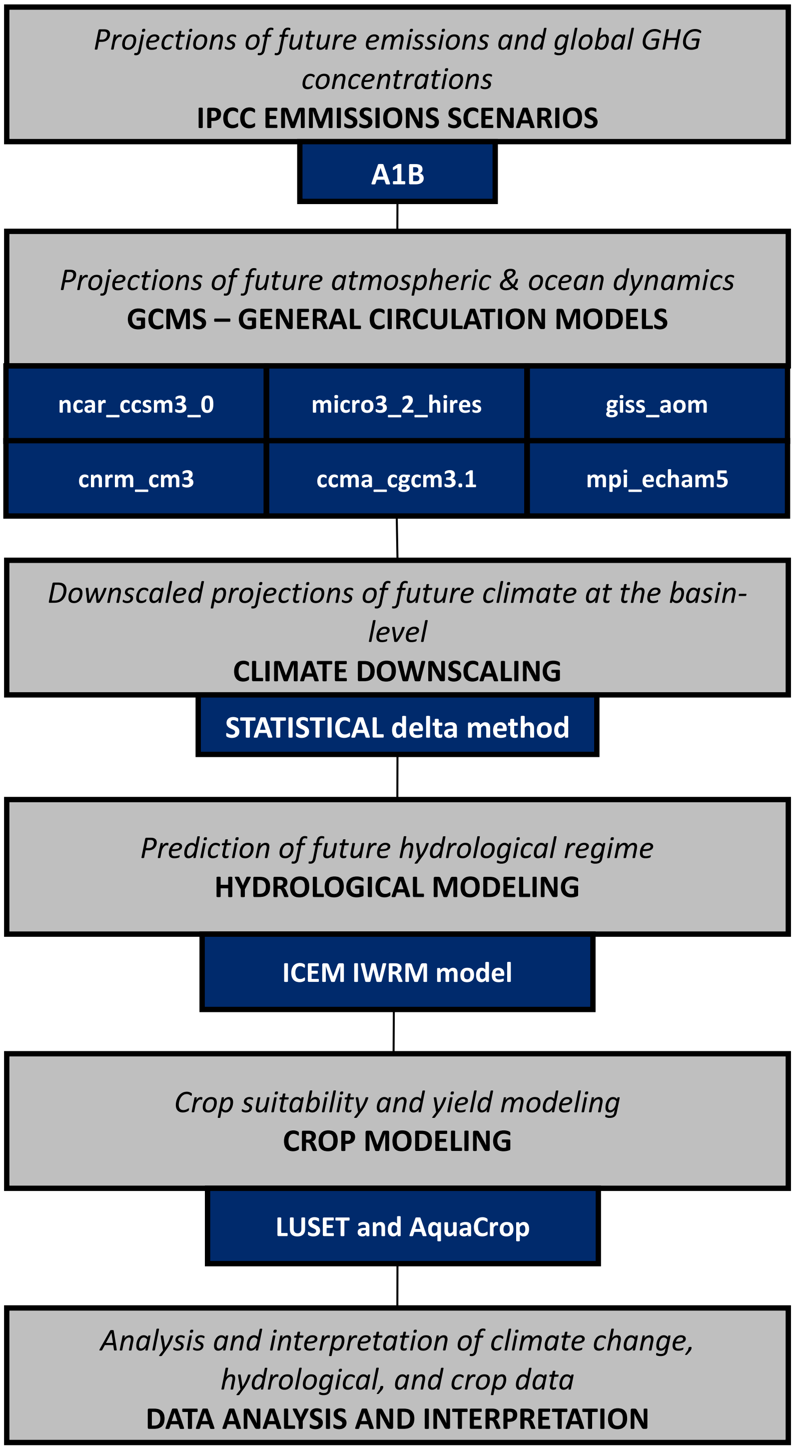

### 3.2.3 METHOD FOR IDENTIFYING CLIMATE CHANGE THREATS

The study followed a common five step process to identify climate threats starting from IPCC emissions scenarios and ending with specific threats at the province level that had been identified as important for the assessment of the vulnerability of key species and systems (Figure 3-14).

Assessing climate change threats—the process of quantifying changes in hydroclimate parameters—utilized a combination of climate and hydrological modeling together with statistical and GIS data analysis. Modeling and downscaling is used to convert scenarios of future GHG emissions to broad-scale changes in climate and subsequently to changes in hydroclimate variables at the regional or local level[8]. Although the broader process is well established there are a number of decision points which have fundamental influence on the final hydroclimate results. Figure 3-14 summarizes the process and decisions made by the study team in selecting IPCC Special Report on Emissions Scenarios (SRES) scenarios, General Circulation Models (GCMs), downscaling techniques, and hydrological and hydrodynamic modeling.

[8] The process has been implemented in over 10 case studies in the Mekong Region. Annex I describes the process in detail.

Figure 3-14: Climate threat modeling workflow

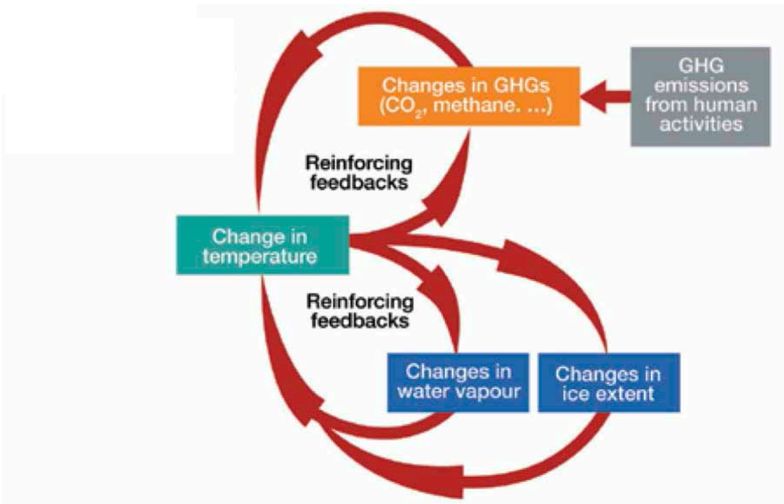


Recent advances in climate modeling recognize the importance of radiative forcing factors with local and regional differences, such as landuse and aerosols. Changes in landuse can impact the surface albedo and moisture balance. Aerosols cause radiative scattering, radiative absorption, and impact on heating and mixing processes. Anthropogenic aerosols are a significant forcing factor in Southeast Asia and have been shown to impact the onset of the monsoon seasons (Eddy et al. 2005, Collier and Zhang 2009). The study team recognizes the importance of these factors and their impact on local and regional radiative forcing but do not explicitly take them into account except to the extent to which they are already incorporated into the GCMs.

#### 3.2.3.1 IPCC emissions scenarios

**Emissions scenarios determine the level of radiative forcing in the atmosphere as the consequence of GHG impacts on atmospheric dynamics**. Predictions of future changes in climate and hydrological variables depend on assumptions made about the release of GHGs from human activities and landuse changes (Figure 3-15). Projections of future emissions are therefore the building block on which climate change threat assessments are made.

**Figure 3-15: Anthropogenic feedbacks in the global climate system** *(Source: AAS 2010)*




**The Study uses IPCC Scenario A1b—a moderate emissions scenario—for all future climate projections**. The IPCC has developed a standardized collection of 40 scenarios that are used globally for climate change assessments and comprise different assumptions of future demographic, technological, and economic development which each lead to different levels of future GHGs (IPCC 2007). IPCC Scenario A1B represents a world of rapid economic growth, introduction of more efficient technologies, global population peaking by 2050 and a balance between fossil intensive and non-fossil energy sources (IPCC 2000). In the decade since the emissions scenarios were defined, monitoring data has shown that global emissions have been equal to or exceeding the highest emissions scenarios.

**For the USAID Mekong ARCC time slices, the variability in projections between emission scenarios is minor compared to other factors**. Only one scenario was used in the study because for the project time-scale, centered on 2050, the variability in IPCC scenarios is approximately 0.5°C for the Mekong region (Eastham et al. 2009), while variations between GCM outputs vary by more than 6°C. This means that for the project time slice the variability between GCMs is far greater than that from different IPCC scenarios. USAID Mekong ARCC resources have therefore been focused on capturing the more important variability between GCMs rather than between emissions scenarios.

#### 3.2.3.2 General Circulation Models

**Multi-model ensembles represent international best practice in understanding changes in the global climate system**. The various GCMs include a full description of atmospheric and ocean circulation dynamics which vary depending on the GCM selected. The varying description of physical approaches leads to varying accuracy for any given GCM over any given area. Because of this variability in results, international best practice in climate change assessment strongly recommends multi-model approaches to climate change modeling (MacSweeney et al. 2011). The use of multiple GCMs allowed the study team to explore the suitability of different GCMs to the Mekong region; the impact of model architecture on climate change results; and focus resources on components contributing the greatest uncertainty to results (i.e., GCMs, not SRES scenarios).

**The study adopted six GCMs that best simulate the historic climate conditions of the Mekong Basin.** These GCMs were selected based on a statistical review of past studies to determine the suitability of the 17 GCMs that have been applied to the Mekong Basin over the past 10 years (Eastham et al. 2009, Cai et al. 2008). The review focused on comparing the ability of the GCMs to simulate historic precipitation data in the Mekong Basin. The six GCMs that exhibited the best agreement for the LMB precipitation regime are:

- i. ccma_cgcm3.1 (CCCMA Canada),
- ii. cnrm_cm3 (CNRM France)
- iii. ncar_ccsm3_0 (NCAR USA)
- iv. miroc3_2_hires (CCSR Japan)
- v. giss_aom (GISS USA)
- vi. mpi_echam5 (MPI Germany)

Further details on the GCM selection process are presented in Annex 1.

#### 3.2.3.3 Climate downscaling

**Downscaling is essential in localizing GCMs to the regional context**. GCMs operate at coarse resolution because of limits to computer processing power (200-400 km grid cells). This resolution is inappropriate for detailed spatial assessment at the basin or provincial level, therefore climate data from the six GCMs was downscaled to the sub-basin level.

**In the Mekong region, dynamic downscaling is a challenge due to the complexity of the Mekong hydroclimate system**. Previous attempts at dynamic downscaling in the region have demonstrated the difficulty in modeling the complex physical processes of the Mekong hydroclimate, where multiple monsoons, snow melt, tropical storms and low-pressure cells, and coastal processes combine. To date, research and understanding on the physical processes and mechanisms behind these features and how they interact are still preliminary. In particular, efforts at dynamic downscaling have shown poor performance in replicating baseline precipitation regimes in the Mekong Basin and results are typically applied using correction factors (see for example MRC 2010).

**Statistical downscaling was used because it is computationally less expensive than other downscaling approaches and it is well suited to downscaling data to point level where long historic records exist**. Statistical downscaling relies on the premise that local climate is conditioned by large-scale (global) climate and by local physiographical features such as topography, distance from the ocean, and vegetation, such that at any specific location there is a link between large-scale and local climatic conditions. Often determining the nature of these links in terms of physical processes can be difficult but by fitting long time series data with a statistical distribution, empirical links can be identified between the large-scale patterns of climate elements (predictors) and local climate conditions (predicted). To do this, GCM output is compared to observed information for a reference period to calculate period factors, which are then used on the rest of the GCM time series in order to adjust biases (Bouwer et al. 2004). Because of the use of correction factors, statistical techniques have been shown to be less accurate in arid climates where future climate trends can be masked by the correction factor, though results have been better for tropical zones(Bouwer et al. 2004). Stations were selected to ensure 25 years of daily observational data (1980–2005) with which GCM results could be validated and checked, providing a total of 151 precipitation and 61 temperature stations and generating a 1980–2100 daily time series at each station for each GCM. Annex 1 provides more details on the statistical downscaling approach, assumptions, and verification.

#### 3.2.3.4 Hydrological modeling

**Distributed water balance model**

The IWRM model is a physically-based, distributed hydrological model and was used to spatially interpolate historical and downscaled climate data between monitoring stations and to simulate the hydrological regime of the basin using a water balance approach. The IWRM is a physically-based model which simulates the actual physical processes of the Mekong hydroclimate for 5x5 km grid cells and for daily time steps. The climate interpolation and hydrology simulation is based on a suite of parameters including elevation and weather information as well as soil and vegetation properties, evaporation, filtration, surface runoff, subsurface runoff, and groundwater transport. By basing the model on the actual physical processes, the team was able to accommodate changes to one or more of these parameters and quantify the impacts on the processes of the hydrological regime—making the model suitable for climate change assessments. The model is highly customizable and was also used to calculate secondary outputs such as soil moisture, crop yield and suitability modeling, and agricultural drought occurrence. GIS analysis was used to analyze and visualize the various model outputs. Annex 1 provides a detailed explanation of the hydrological modeling approach.

Hydrology was quantified as flow and water levels for seven pre-existing gaging stations along the Mekong mainstream between Chiang Saen and Kratie[9]. The hydrology below Kratie was not modeled using the IWRM model because below this point the river enters a broad floodplain and flow is complicated by overland and non-channelized flow.

**Additional crop suitability and crop yield modeling was built into the IWRM model.** This is described further in the agriculture methodology in Section 5.1 and in Annex 1.

A complete list of hydroclimate parameters outputs from the IWRM model is listed in Table 5. These outputs were available at a daily time step for each grid cell.

[9] Stations include: Chiang Saen, Luang Prabang, Vientiane, Mukdahan, Pakse, Stung Treng and Kratie

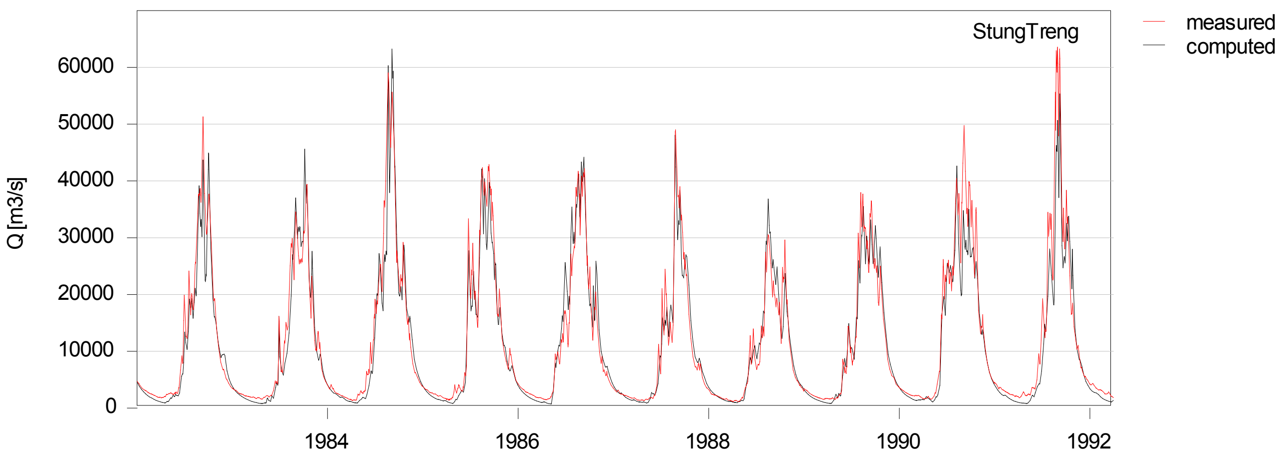
**Table 5: IWRM Model output parameters**

| Parameter | Unit / Description |
|---|---|
| Minimum Temperature | °C |
| Maximum Temperature | °C |
| Potential Evaporation (PET) | mm |
| Potential evapotranspiration | mm |
| Precipitation | mm |
| Stream/River flow | $m^3/s$ |
| Stream/River water levels | masl |
| Runoff | mm |
| Surface soil water (<0.5m deep) | mm |
| Sub (>0.5m deep) | mm |
| Groundwater level | masl |
| Hillslope erosion | $kg/m^2$ |
| Sediment load | $kg/m^2$ |
| Ponded surface water level | masl |
| Land suitability (for crops: rainfed rice, maize, cassava, rubber, Robusta coffee, soya bean) | 0-100 |
| Crop yields (rice, maize) | t/ha |
| Agricultural drought (PET > 2 x Precipitation) | No. months |

## Model calibration

Stung Treng was selected for calibration instead of the further downstream Kratie station based on data quality considerations. Assessment of the model calibration at Stung Treng indicates a strong statistical correlation between the observed and simulated data for the baseline period 1980–2005 with an $R^2$ value of 0.93 (Figure 3-16).

**Figure 3-16: Observed (red line) and computed (black line) daily flows at Stung Treng station** *(Lauri 2011)*



### Extreme Flood Return Periods

As an input into the flood modeling, the study calculated how the 1 in 100 year magnitude flow event at Kratie would increase due to climate change. Frequency analysis uses probabilities to express the likelihood of an event occurring based on fitting statistical distributions to time series data. Return periods express the likelihood that a certain value will be exceeded—for example, the P1% or 1 in 100-year flood indicates that there is annually a 1% chance of a flood exceeding or equal to that flood. The selection of the appropriate return period is then determined by the significance of exceedence.

Central to statistical methods used in frequency analysis is the assumption that the time series can be approximated as stationary—that is, key statistical parameters (mean, variance) are approximately constant over very long periods (Chow et al. 1988). In the context of climate change, it is clear that time series for hydro-meteorological phenomena are non-stationary—that is the values for the mean, variance and mode are dynamic and changing over time. This presents a challenge for the use of extreme event analysis. Climate change assessments have one of two options:

(i) ***Assume stationarity*** of the long term time series and combine historic and future time series into one record and conduct frequency analysis over the entire data set.

(ii) ***Acknowledge non-stationarity*** by disaggregating future time series data from past time series data and undertake frequency analysis on each data set separately. This means that the future hydro-meteorological regime is seen to have undergone a fundamental shift from the historic regime to a new regime. Frequency analysis is then applied on the future CC time series independent on the past time series.

In choosing how to approach frequency analysis with climate change each option comes with a set of assumptions and implications for the assessment. From a risk management point of view, Option 2 is more cautious as the changes in magnitude and frequency of extreme events will be greater when decoupled from historic data; option 1 is more conservative and has the potential for underestimating the magnitude of change. The study team undertook the frequency analysis assuming the conservative stationarity assumption (Option 1).

Analysis was undertaken to determine the return periods for Kratie station under baseline conditions. A historic annual maxima series for daily peak flows was developed for 86years of gaging station data available from the MRC (1924–2009). The data was then fitted to an extreme value distribution (EV1) and return periods calculated using the methodology outlined by Chow et al. (1988) for peak flows at Kratie. The calculated extreme event frequency distribution was then compared to that calculated by the MRC for the same station (Kratie) and parameter (peak discharge) and using a baseline period of 1924 to 2006 (Table 6).

**Table 6: Calculation of historic return periods for extreme flows at Kratie Station (1924–2006/9)**

| Return Period (T) | Annual Exceedance Probability (%) | MRC* Peak Q ($m^3/s$) (1924–2006) | This Study Peak Q ($m^3/s$) (1924–2009) | % variability from MRC estimate |
|---|---|---|---|---|
| 2 year | 50% | 52,000 | 52,745 | +1.4% |
| 5 year | 20% | 58,000 | 58,309 | +0.5% |
| 10 year | 10% | 63,000 | 61,992 | -1.6% |
| 20 year | 5% | 68,000 | 65,526 | -3.6% |
| 100 year | 1% | 78,500 | 73,527 | -6.3% |

**Source: MRC 2011*

Estimates by the present study produced marginally higher estimates for high-frequency events (return periods of less than 5 years), and lower estimates for infrequent events with return periods greater than 5 years, compared to the MRC estimates.

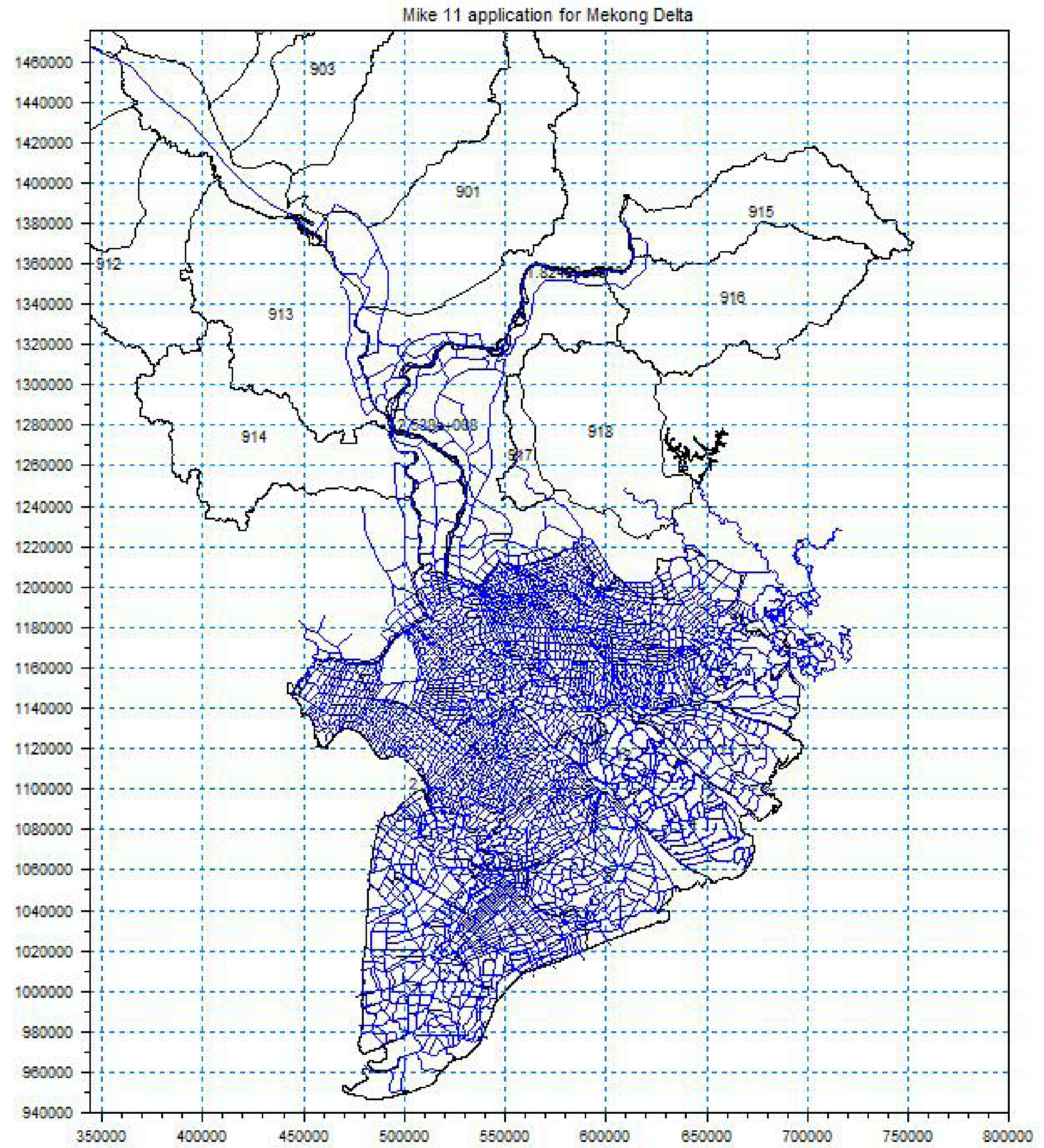
The future daily flow was calculated for Kratie over the period 2045–2069 using six GCMs, providing a total of 168 hydrological years of daily data. For each GCM, the 25 year future data set was then coupled with the 86 year historic baseline and then fitted with the EV1 distribution to calculate magnitudes and return periods.

#### 3.2.3.5 Flood modeling

Vietnam is ranked high globally in terms of climate change vulnerability primarily because of its low-lying topography and long coastline, which makes it susceptible to sea level rise and flooding. This is particularly relevant in the Mekong Delta where the combined effects of increasing Mekong flows and rising sea levels may lead to major changes in the flood regime. The study used a MIKE 11 hydrodynamic model to quantify the changes in depth and duration of flooding and saline intrusion due to changes in upstream hydrology, sea level rise, and cyclones.

The MIKE 11 model contains detailed topographic, infrastructural, canal network, water demand, hydro-meteorological, water quality, and landuse information that it combines into a hydraulic representation of the delta and Cambodian floodplains (Figure 3-17). The MIKE 11 model used the hydrologic IWRM model to establish boundary conditions of flows entering from upstream and the 2011 tide conditions with and without sea level rise as the seaward boundary condition. The model set-up includes more than 3,900 rivers and canals and more than 5,000 hydraulic works representing irrigation and drainage sluices as well as overland flood flow to the flood plain via low-lying parts of roads. The model divides the delta into 120 zones and utilizes more than 25,900 water level and 18,500 flow points to calculate small-area water balances. The model has been calibrated using the 2000 flood year and validated with the 2001 flood year. Further detail on the flood model and calibration is presented in Annex 1.

**Figure 3-17: MIKE 11 hydraulic schematization for the Mekong Delta:** *showing the complexity of the hydraulic interactions, which includes rivers, canals, irrigation and drainage sluices, and overland flood flows.*




## Scenarios

Five scenarios were selected to assess the impact of climate change on flood depth and duration and two for analyzing impacts on salinity intrusion (Table 7).

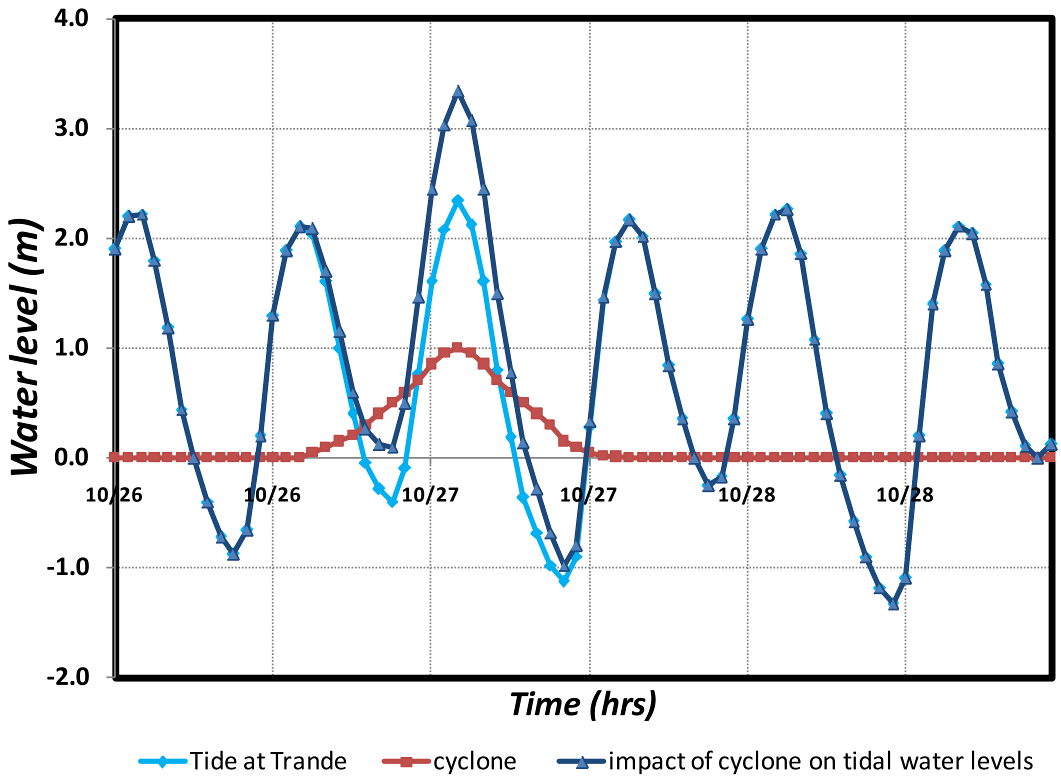
**Table 7: Mekong Delta flood and salinity modeling scenarios**

| Scenario | Parameters assessed | | | |
|---|---|---|---|---|
| | Maximum flood depth | Duration of 0.5 m/ 1.0 m depth flood | Maximum salinity concentration | Duration of 4 ppt salinity concentration |
| **Baseline climate** with average flood | x | x | x | x |
| **Baseline climate** with 1 in 100 yr flood | x | x | | |
| **Future climate** with average flood and 0.3 m SLR* | x | x | x | x |
| **Future climate** with 1 in 100 yr flood and 0.3 m SLR | x | x | | |
| **Future climate** with 1 in 100 yr flood, 0.3 m SLR, and cyclone | x | x | | |

* Sea level rise

One of the climate change scenarios included consideration of tropical cyclone impacts on the delta through the superimposition of observed data from Cyclone Linda, which hit the Mekong Delta on the 5th November 2007. Consideration of cyclone impacts is complicated by the interplay of physcial processes in the coastal system. Analysis of observed data from Cylone Linda indicated that the impact of the cyclone on peak water levels is strongly dependent on the timing of cyclone impact and whether this coincides with a spring tide. If a cyclone occurs during average or low tide conditions then water levels would not be out of the normal tidal range. For example, during Cyclone Linda the maximum water level at the Bassac River mouth reached 1.90 m whereas during the spring tide of the same year the water level reached 2.08 m when no cyclone was present. To assess the maximum affect that a cyclone may have on flooding, the study modeled the flood conditions for when the maximum increase in water level by a cyclone occurs at the exact same time as a spring tide (Figure 3-18).

**Figure 3-18: Development of climate change with tropical cyclone scenario:** *Timing of cyclone impact (red line) was superimposed to coincide with spring tide conditions (light blue line) to produce peak storm surge (dark blue line) as the summation of both factors*






### Boundary Conditions

The flood model was set up to cover the Mekong River floodplain from Kratie to the South China Sea requiring upstream and downstream boundary conditions.

- **Upstream boundary conditions** represented daily discharge data at Kratie station for each of the baseline and future climate scenarios—that is baseline and future hydrographs for average and 1 in 100 year conditions.
- **Downstream boundary conditions:** Analysis of historical data indicates that flooding in the delta is strongly determined by tidal fluctuations which were set using the spring tide conditions from the 2011 hydrological year. Under climate conditions a sea level rise of 0.3 m was added to the base tidal condition of 2011. For the fifth scenario cyclone forcing was included in the downstream boundary condition.

### 3.2.3.6 Climate change threat profiles

**Climate change modeling results must be analyzed and presented in a way that is useful to specialists from other disciplines (see Box 1).** Raw output from the modeling includes 25 years daily time series for a wide range of parameters[10] not all of which are useful to the theme analyses. The modeling team therefore consulted extensively with the theme groups to identify the

[10] Raw output parameters include 25 year time series of daily maximum and minimum temperature, precipitation, mainstream station flows, evaporation and soil water availability.

hydroclimate parameters for which robust causal linkages to impact pathways could be established for each theme (Figure 3-19).

The raw outputs from the modeling were processed to localize changes to priority provinces. Points were identified in each priority province which represented the average climate for the province. In some provinces two point locations were used due to highly varying climate caused by elevation and other factors. At each representative point location statistical analysis was used to draw out the results for the 20 hydro-meteorological parameters identified by the theme groups as essential to interpreting the vulnerability of their key species and systems (Figure 3-19). Results included parameters such as mean annual rainfall, occurrence of consecutive hot days, frequency of drought, temperature exceedance curves, duration of flood season, or number of rainy days during the wet and dry season.

The results were then compiled into climate change threat profiles for each priority province; each profile presents results in map and graph form for the important parameter characteristics. The climate change threat profiles are specifically developed to be comprehendible to specialists of other disciplines. The province climate change threat profiles were distributed to the theme groups as inputs to their vulnerability assessments.



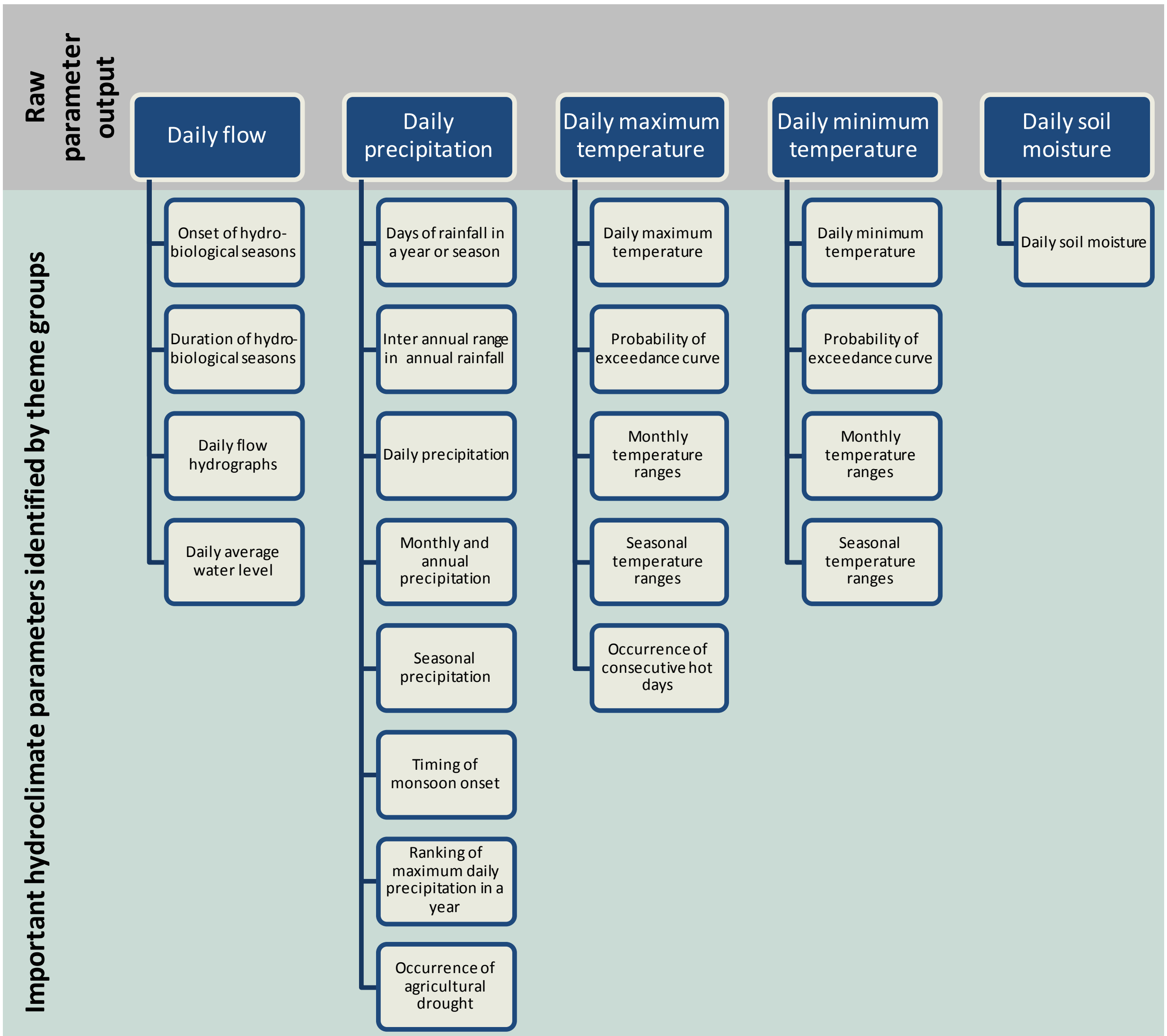
**Box 1: Communicating climate change**

Globally it is convention for the scientific community to present changes in temperature in absolute terms such as +2°C. However, the significance of an increase in temperature varies from region to region, or even within regions—the impact of an increase of 2°C in the Tibetan plateau will vary significantly from a 2°C increase in the Mekong Delta. This is because the significance of change in a hydroclimate parameter is largely relative to the baseline conditions. For most hydroclimate parameters, percentage change is the best way to capture the relative magnitude of change and is widely used throughout this report to complement the quantification of absolute change (e.g., in stream flow, flood extent, precipitation, etc.). However, when expressing a temperature change as a percentage, we technically must use a temperature scale whose zero point is the temperature of absolute zero[11], called the Kelvin scale. All other temperature systems, like Fahrenheit and Celsius, have arbitrary "zero points", and calculations of percent temperature change using these scales give arbitrary results. At the same time, the Kelvin scale is hardly used outside the scientific community and as climate scientists it is important to communicate climate change modeling results in a way that is easily understandable to the intended audience, in this case communities, policy makers, and specialists from other disciplines.

The study team decided to complement the quantification of absolute changes in temperature within this report with percentage changes using Degrees Celsius. These percentage changes in the report are therefore qualitative and meant only to compare the relative significance of change between different areas within the basin as a guide for setting adaptation priorities. Actions taken in response to these priorities should always refer back to the absolute changes.

[11] Absolute zero or 0 K is approximately equivalent to -273°C

**Figure 3-19: Shortlist of important parameter characteristics for the species and systems chosen by the theme groups**




## 3.3 HOTSPOT RANKING METHOD

**Hotspot ranking methodology was used to help governments, donors, and other stakeholders focus their adaptation efforts on those communities and regions most exposed to climate change threats.** An important objective of the study is to identify climate change hotspots within the basin—or within the geographic areas where projected changes are likely to be most significant. The purpose of taking a hotspot approach in the study is to help set priorities at the basin scale for a region which is immense in size, in the diversity of rural livelihood and natural systems assets, and in the magnitude of projected climate changes.

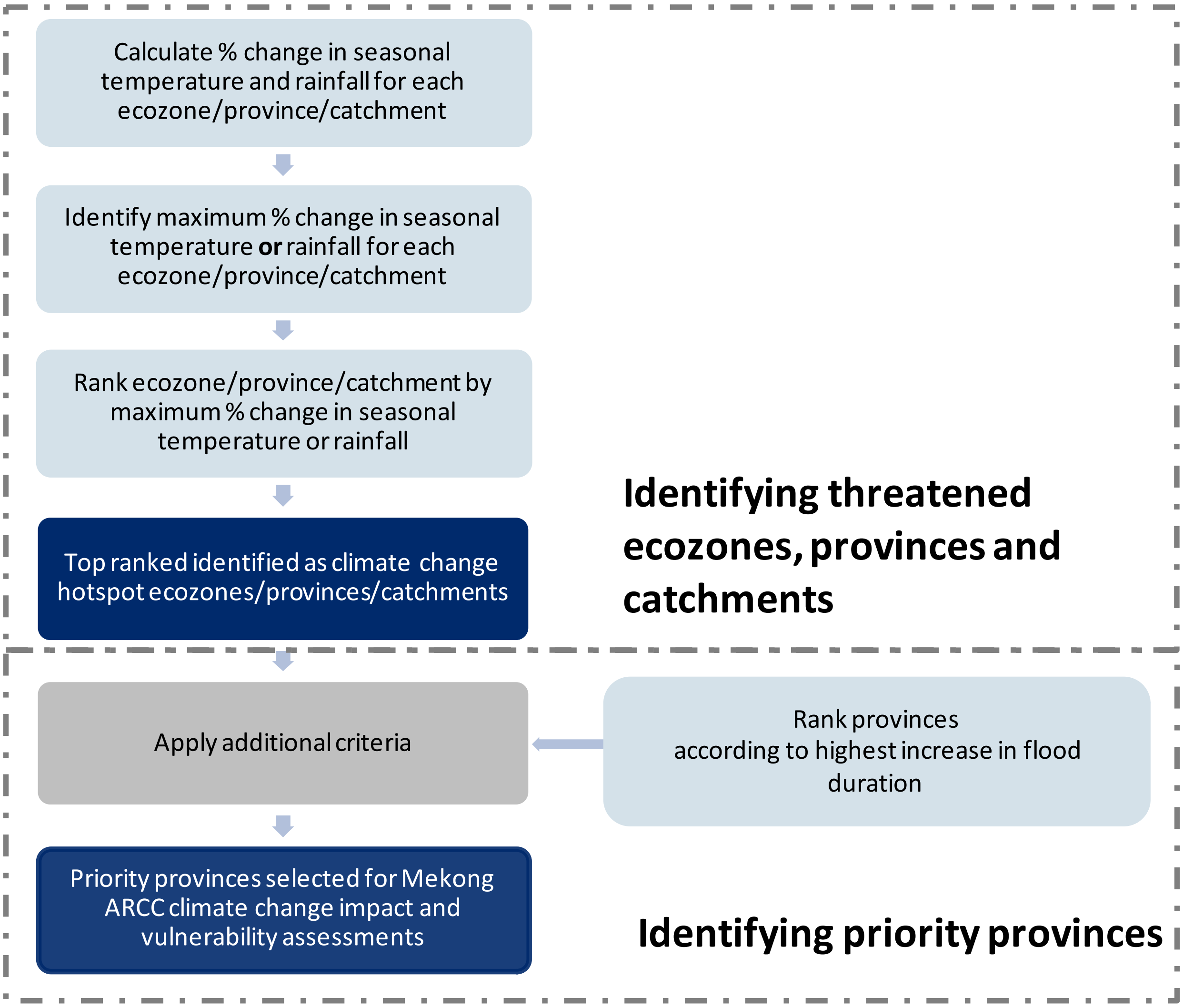
**The hotspot approach helps to integrate and orient study analysis and findings spatially and provides a scientific basis for the selection of focal areas** for the community adaptation initiatives that will be undertaken in subsequent USAID Mekong ARCC phases. The study identified hotspot areas at various spatial scales including ecozone, catchment, province, and protected areas.

### 3.3.1 HOTSPOT THREAT ANALYSIS

**The study took a threat-analysis approach to identifying hotspots**. The method involved identifying areas projected to experience the greatest magnitude of change in climate threat parameters (Figure 3-20). *The hotspots reflect only the predicted levels of climate change threat – they do not take into account the actual impacts (positive or negative) of those threats or other factors that influence capacities to respond to impacts such as the relative level of poverty within a given area.* Five parameters were used to assess the magnitude of climate threat in each area:

- (i) Wet season daily maximum temperature
- (ii) Dry season daily maximum temperature
- (iii) Wet season daily precipitation
- (iv) Dry season daily precipitation
- (v) Flood duration including catchment (rainfall and runoff) and coastal (sea level rise and storms) drivers.

**Figure 3-20: Hotspot ranking process**




Hotspot ranking was undertaken for three basic spatial units; provinces (88), ecozones (12), and tributary subcatchments (104), arriving at three hotspot rankings.

Using GIS analysis the average percentage change in seasonal daily maximum temperature and daily precipitation for the areas was calculated. The areas were then ranked based on the highest seasonal daily maximum temperature change or daily precipitation change—i.e., an area that is projected to experience a large wet season or dry season change in temperature or precipitation is identified as a highly threatened area.

For provinces, *projected flood duration* was also considered because it is a threat that will have significant impacts on the lower sections of the LMB. Consideration of floods caused by sea level rise, rainfall and runoff, and storm surge informed the ranking of delta and Tonle Sap provinces in terms of increases in the duration of floods of greater than 0.5 m or 1.0 m. Therefore an area that is projected to experience a large increase in the duration of flooding is rated as highly threatened.

Additional factors were taken into account when identifying the priority provinces for which the theme groups would undertake their vulnerability assessments (Figure 3-20). The following additional criteria were applied to ensure that all themes and areas of the basin were represented:

- Representation of all ecozones

- Representation of the delta area by including provinces ranked highly threatened by flooding
- Representation of each of the thematic sectors (fisheries, agriculture, livestock, natural systems and socio-economics)
- Representation of all four countries.

Because the study chose a threat analysis approach to identifying hotspots—rather than a vulnerability approach—the ranking does not reflect judgments on whether the threat will lead to positive or negative impacts. It may be possible that an increase in precipitation or temperature will be beneficial for plant growth, as an example. The study approach identifies the most extreme changes and then conducts impact and vulnerability assessments of the hotspot areas to inform and guide adaptation responses for the species and ecosystems represented.

## 3.4 SPECIAL METHODS ADOPTED FOR THE MAIN THEMES

### 3.4.1 AGRICULTURE

#### 3.4.1.1 Agriculture Trends

To assess trends in the agriculture sector in the different ecozones, representative provinces were selected in each ecozone based on GIS analysis. For each ecozone, one or more provinces with more than 50% of its surface area within the zone were selected to illustrate the agricultural production sectors. Additional provinces with less than 50% of their surface area within the ecozone but designated as representative "hotspots" by the study team were also included in the baseline assessment of all sectors (livestock, fisheries, agriculture, natural systems, and health and rural infrastructure). Provincial time series data of planted and harvested areas and production of different crops were obtained from websites of the statistical offices of riparian countries.[12] In addition, data were used from the *Regional Data Exchange System on food and agricultural statistics in Asia and Pacific countries* maintained by the FAO Regional Office for the Asia Pacific Region (http://www.faorap-apcas.org).

Crop selection for the agriculture baseline was based on the main crops and forestry species found in the LMB in terms of (i) total area of production, and (ii) crops that have significantly increased in the past 12 years in terms of production and cultivated area in the different ecozones. The following crops were selected for the baseline and vulnerability assessment: rainfed rice (*Oryza sativa*), upland rice, lowland rainfed rice, irrigated rice, maize (*Zea mays*), cassava (*Manihot esculenta)*, soybean (*Glycine max*), sugarcane (*Saccharum officinarum*), rubber (*Hevea brasiliensis*) and Robusta coffee (*Coffea canephora*).

#### 3.4.1.2 Vulnerability assessment and modeling

The Land Use Evaluation Tool (LUSET) model developed by IRRI (CGIAR-CSI 2006) and used in Vietnam (Yen et al. 2006) was applied to evaluate the potentials for agriculture development within the basin. The model is based on two input interfaces (or modules): the crop requirement module and the land unit information module. For each Land Unit (LU) the suitability of the area for growing pre-defined crops is calculated using the characteristics of the land units and the crop requirements.

[12] In Lao PDR (http://www.nsc.gov.la/) for the period 2005-2010 and Vietnam (http://www.gso.gov.vn/default_en.aspx?tabid=491) for the period 2000 to 2009

The crop requirements are divided into four main groups and are based on the predefined crop requirements found in Sys et al. (1993) and modified with local expert knowledge and data from an FAO database, Ecocrop (http://ecocrop.fao.org/ecocrop/srv/en/home). There is no soil survey with detailed soil characteristics for the entire basin. Therefore, the analysis was limited to climate suitability. Suitability values for specific crops were calculated for each of the land unit characteristics: temperature and water. An *Overall Suitability Value* (OVS) combining temperature and water characteristics was obtained after a two-step calculation and was then transformed into an *Overall Suitability Rate* ranging from 1 (not suitable) to 100 (highly suitable).[13]

The crop yield modeling is based on the AquaCrop model developed by FAO coupled with the IWRM model. The model used daily projected climate data, including temperature and rainfall, from six global models and crop yield was calculated by integrating AquaCrop into the IWRM model. Rice and maize yield predictions were calibrated using the average yield for the selected provinces. The average crop yield is presented in the study results based on the six global models used.

### 3.4.2 LIVESTOCK

#### 3.4.2.1 Criteria for livestock species/systems selections:

Livestock systems representing over 95 percent of livestock production systems in the LMB were selected for baseline and vulnerability assessment, and subsequent adaptation recommendations. The process of selecting livestock species and systems for the study combined the following criteria:

- Contribution to regional livestock numbers on the basis of total stock, livestock units (LU), number of households raising the particular species, and stock densities
- Estimated monetary and employment contribution to local/national economies
- Broader consideration of contribution to household livelihoods including monetary and non-monetary value and contributions to food security
- Contribution to global genetic diversity (indigenous breeds)
- Projected importance to regional production and consumption in the medium-term.

Livestock systems were assessed against these criteria using a number of national data sets, secondary sources, expert discussions, study team experience and professional judgments. A number of important wild species were also considered as indicators of effects of livestock and other sectors on related wild ungulate and bird populations.

Table 8 summarizes the systems and species considered in the full baseline evaluation, the vulnerability assessments, and in developing adaptation strategies at hotspot and basin-wide levels.

[13]The OVS is categorized into 7 classes of suitability: S1: very high suitability (85–100); S2: high suitability (75–85); S3: good suitability (60–75); S4: moderate suitability (40–60); S5: Low suitability (25–40); S6: marginally suitable (10–25) and S7: not suitable (0–10)

**Table 8: Livestock systems and species assessed in the Mekong Climate Study**

| Livestock Type | Livestock System | Livestock Purpose |
|---|---|---|
| **Bovines: cattle, buffalo** | Smallholder cattle/buffalo 'keeping' | Draft |
| | Smallholder cattle 'keeping' | Beef |
| | Dairy | Dairy |
| **Pigs** | Small commercial pig | Fatteners/breeders |
| | Smallholder low-input pig | Integrated |
| **Poultry** | | |
| **Chickens** | Scavenging chicken | Dual purpose |
| | Small commercial chicken | Broilers |
| | | Layers |
| **Ducks** | Field running layer ducks | Layers |
| **Wild Species** | | |
| **Banteng, saola, gaur, kouprey, eld's deer, *Sus scrofa* spp., wild poultry** | | |

### 3.4.2.2 Vulnerability assessment methodology:

Livestock system tolerances, in terms of productivity, were established on the basis of regional and international animal science research and assessed against the climate change projections developed by the study team. Expert judgment was used in the application of the CAM methodology to assess the impacts and level of vulnerability of each livestock system to specific climate change threats expected in the geographic area under assessment.

The detailed rationale for the vulnerability assessment rankings are provided in the full livestock theme report. The influences on exposure, sensitivity, and adaptive capacity to climate changes for livestock systems are outlined in Table 9.

**Table 9: Influences on exposure, sensitivity, and adaptive capacity for livestock systems**

| Exposure | Sensitivity | Adaptive Capacity |
|---|---|---|
| System prevalence in the location | Each species/breed has differing tolerances | Species/breeds have different adaptive capacity |
| Duration of the extreme climate or hydrological event | Livestock housing system influences sensitivity | Availability of feed from existing and other feed sources (**) |
| Frequency of the extreme event | Feeding systems influence sensitivity | Production system (e.g., free range or battery) |
| Severity of the extreme event | Animal health (typical vaccination rate, level of biosecurity employed) | Accessibility of animal health/extension services (cost, quantity, quality, reputation) |
| Location of stock relative to the extreme event* | Value to household of their livestock assets as part of their overall livelihood (cost of losses, livelihoods, food security)** | Outbreak responses (surveillance, compensation etc.) |
| Location of relevant assets (feedstock, housing, etc.)* | | Household wealth status** |

**Relates primarily to extreme events, in terms of exposure, but also locality-specific impacts of other climate changes. Requires location-specific assessment.*
***Location-specific assessment required.*

### 3.4.3 NATURAL SYSTEMS – NTFPS AND CWRS

The natural systems theme group was given two distinct tasks. One was to assess the vulnerability and adaptation requirements of individual NTFP and CWR species as examples of ingredients in most farming systems in the basin. The other task was to take an ecosystems approach to assessing the vulnerability and adaptation requirements of five clusters of protected areas including the individual areas that had been ranked as most vulnerable to a range of climate change threats.

The analysis of the NTFPs and CWRs was species based, while the protected areas analysis looked at assemblages of plant and animal species and their relationships as part of an area-wide assessment of farming ecosystems. Naturally growing NTFPs and CWRs are not always restricted to protected areas—some are found in wasteland, field margins and roadside ditches. However, their original habitats are closely related to the forests and wetlands found in PAs. The PAs are therefore the main refuge for these species.

#### 3.4.3.1 Farming ecosystems

**Farming ecosystems** go beyond farm holdings to include the harvesting and use of wild plant and animal species that were once widely distributed throughout the region, but are now restricted to forested areas both within and outside protected areas. Natural wetland areas are included in this definition. The gathering of wild species is closely integrated with other forms of traditional farming, providing a range of livelihood activities that complement crop cultivation, livestock husbandry, and small-scale aquaculture.

***NTFPs** include all the materials collected from natural or man-made forests and riverine habitats and used to support local livelihoods.* NTFPs include items such as forest and aquatic vegetables, fruit, traditional medicine products, wild animals and aquatic organisms such as fish, mollusks, insects, and crustaceans. While the term NTFP implies non-timber items, it does include wood products for home construction, fuel wood and charcoal, and handicraft products (NAFRI et al. 2007).

**CWRs** *are all those species found growing in the wild that to some degree are genetically related to food, fodder and forage crops, medicinal plants, condiments, and ornamental species*. Compared to NTFPs, CWRs are often forgotten by all except agricultural crop researchers. They do not necessarily have an economic or even subsistence value as do NTFPs. They are important as a source of genetic materials for the improvement of existing crops, including the development of resistance to disease and extremes of temperature and drought. CWRs exist side by side with NTFPs in forests and in small patches of unused land.

The region also has a wide range of **landraces** and relatives of many economic plants that are well-known as the region's exports in the world market, e.g., durian, mangosteen, rambutan, jackfruit, and mango. *A landrace is a local variety of a domesticated animal or plant species that has developed largely by natural processes through adaptation to the natural and cultural environment in which it lives.* It differs from a formal breed, which has been selectively bred to conform to a particular formal, purebreed standard of traits. **Landraces** are usually more genetically and physically diverse than formal breeds.[14]

#### 3.4.3.2 Choice of NTFP and CWR species

**NTFPs:** Because of the vast diversity of plant and animal species that are used in so many different ways by the people of the Mekong River Basin, it has been necessary to focus on a relatively small number to develop a typical set of NTFPs that can be examined for their tolerance and responses to

[14] http://en.wikipedia.org/wiki/Landraces#Plants

climate changes. The species chosen are not representative in the sense that findings can be extrapolated to other species of similar plant type or as representative of the ecological characteristics of the hotspots. They are provided more as examples of commonly used NTFPs and as case studies of vulnerabilities to climate change that can be expected in the different climate change hotspots. The criteria for selecting NTFPs were species: (a) from different plant types, (b) with economic or livelihood importance, (c) that served as examples from the different ecozones, and (d) for which information on ecological and climate preferences or tolerances is available.

NTFPs were selected and categorized according to the following plant types or forms: mushrooms, grasses and herbs, aquatic plants, climbers, orchids, bamboos and rattans, shrubs and trees.

Several species of invertebrates including insects and earthworms were selected, representing animal NTFPs. These also have an ecological importance providing services such as pollination and breakdown of organic materials in the soils. Table 10 shows species in five of the priority provinces for which vulnerability assessments were undertaken, together with the relevant ecozones.

**Table 10: NTFP species identified in each priority province**

| Province | | | Kien Giang | Mondul Kiri | Gia Lai | Chiang Rai | Khammouan |
|---|---|---|---|---|---|---|---|
| Ecozone | | | 3. Delta Low lying acidic area swamp forest | 6. Low-elevation dry broadleaf forest | 9. Mid-elevation dry broadleaf forest | 4. High-elevation moist broadleaf forest - North Indochina | 7. Low-mid ele moist broadleaf forest |
| **NTFP Category** | **Species** | **Common name** | 2. Delta mangroves and saline water | 9. Mid-elevation dry broadleaf forest | | 12. Upper floodplain wetland, lake (CS to VTE) | 4. High-elevation moist broadleaf forest - North Indochina |
| Mushroom | Russula sp | | | x | x | x | x |
| Grasses/herbs | Ammomum spp | False Cardamom | | x | x | x | x |
| Aquatic plants | Sesbania sesban | Egyptian pea | x | | | x | |
| | Typha orientalis | Oriental rush | x | | | | |
| | Lepironia articulata | Lepironia Sedge | x | | | | |
| Climbers | Dioscorea hispida | Bitter yam | | x | x | | x |
| Orchids | Dendrobium lindleyi | | | x | x | x | x |
| Rattans | Calamus crispus | | | x | x | x | x |
| Shrubs | Broussonetia papyrifera | Paper mulberry | | x | x | x | x |
| Trees | Dipterocarpus alatus | | | x | x | x | x |
| | Sonneratia sp | Mangrove apple | x | | | | |
| Insects | Apis dorsata | Giant honeybee | x | x | x | x | x |
| | Red ants | Red Ants | | x | x | x | x |
| Invertebrates | Earthworms | | x | x | x | x | x |

**CWRs:** These require a slightly different approach from that taken with NTFPs, largely because they are not specifically targeted for economic or livelihood use. Although there are a large number of CWRs found within the Mekong region, the focus for this study is on different species of wild rice. The rationale for this focus is that wild rice species are found throughout the region, with different species in each of the ecozones and because there is more information on their ecological and climate tolerances than for other CWRs. The vulnerability assessments were carried out on three wild rice species and one landrace—floating rice, as an example of CWRs.

Table 11 lists the wild rice species considered in each of the five priority provinces, together with the relevant ecozones.

Table 11: Wild rice species identified in each priority province

| Wild Rice | | Kien Giang | Mondul Kiri | Gia Lai | Chiang Rai | Khammouan |
|---|---|---|---|---|---|---|
| | | 3. Delta Low lying acidic area swamp forest | 6. Low-elevation dry broadleaf forest | 9. Mid-elevation dry broadleaf forest | 4. High-elevation moist broadleaf forest - North Indochina | 7. Low-mid ele moist broadleaf forest |
| | | 2. Delta mangroves and saline water | 9. Mid-elevation dry broadleaf forest | | 12. Upper floodplain wetland, lake (CS to VTE) | 4. High-elevation moist broadleaf forest - North Indochina |
| O. granulata | | | | | x | |
| O. nivara | | x | x | x | x | x |
| O. officinalis | | x | x | x | x | x |
| O. ridleyi | | | | | | |
| O. rufipogon | | x | | | x | |
| O. sativa/prosativa | Floating rice | An Giang | | | | |



### 3.4.3.3 Development of database

Baseline information on the species selected has been collated into a simple database that describes:

- Common name, latin name, family, type of plant
- Description, flowering period, fruiting period
- Use and parts used, harvesting and processing, importance and value
- Ecological requirements - latitude range, elevation range, soils preference, forest type
- Climate requirements - temperature range, rainfall range
- Distribution: globally and specifically in Cambodia, Lao PDR, Thailand, Vietnam
- Trends and threats
- Sources of information

The information available on NTFPs and CWRs is patchy. Databases such as FAO's Ecocrop[15] were used to fill gaps where ecological information is available on similar species or species in the same family. This baseline database of the selected species was used as an input to the vulnerability assessments and narrative discussions found in other sections of this report. Typically one species has been selected as an example (but not as representative) of the plant type and a vulnerability assessment carried out on this species.

The ubiquitous nature of many NTFPs means that it was not always possible to be precise about the ecozones where they are found. As reflected in their name, NTFPs are generally found in forests. While their main habitats may be given as evergreen or secondary mixed deciduous or dipterocarp forests, they are often found in other forest types. Thus comparisons of locations within a country or altitude ranges were necessary to arrive at an approximation for the ecozone where each NTFP is most commonly found. In addition, some NTFPs may be found in association with cultivated areas and so have a wider distribution. The aquatic plant NTFPs found in the delta and other floodplain areas are easier to locate.

### 3.4.3.4 Vulnerability assessment method

The natural systems theme group used another ICEM vulnerability assessment method for NTFPs and CWRs which focuses on species. The method is based on one developed by ICEM in 2012 for the MRC as part of a study on the climate change vulnerability of wetlands in the LMB (ICEM 2012). It

[15] http://ecocrop.fao.org/ecocrop/srv/en/home

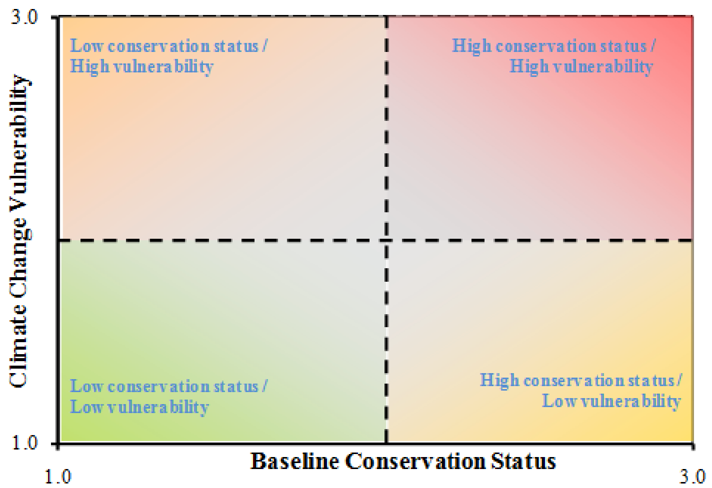
was developed to consider the vulnerability of individual wetland species and habitats and it was found to be readily adaptable for the consideration of NTFP and CWR species.

It is a rapid assessment method that consists of a series of questions about i) the non-climate vulnerability and existing threats to the species and ii) the climate change threats, habitat protection, sensitivity, and adaptive capacity. Answers to the questions are scored on a simple range (1–3) according to the contribution made to the existing and future climate vulnerabilities, and the results of the two sets of questions are averaged to give overall scores for the current non-CC vulnerability and future climate vulnerability. Division of the scores into ranges from *Very Low*, *Low*, *Moderate*, *High*, to *Very High* vulnerability (Table 12) enables the plotting of each species considered in a quadrat diagram, as illustrated in Figure 3-21 and in each profile of the species assessed. This quadrat diagram provides a visual of where the species stands in terms of its current non-CC vulnerability and its future climate change vulnerability. Comparison of the quadrat diagrams in different provinces where the species occurs allows an understanding of the differences between hotspot provinces. The findings for each species have been aggregated and plotted together to allow a prioritization of adaptation measures.

**Table 12: Scoring intervals for climate change vulnerability**

| Category Interval 0.4 | Low | High |
|---|---|---|
| Very High Vulnerability to climate change | 2.7 | 3 |
| High Vulnerability to climate change | 2.3 | 2.6 |
| Moderate Vulnerability to climate change | 1.9 | 2.2 |
| Low Vulnerability to climate change | 1.5 | 1.8 |
| Very Low Vulnerability to climate change | 1 | 1.4 |

**Figure 3-21: Quadrat diagram showing existing conservation status of the species and climate change vulnerabilities of the species**




The questions in the baseline non-CC vulnerability assessment relate to the biology and distribution of the species, the existing threats, and the protection or management afforded it in protected areas. This part of the questionnaire is unlikely to change in different parts of the basin. The second section assesses the climate vulnerability of the species. The first part of this section interprets the threats to this particular species from the climate changes predicted for the particular province or protected area. It uses the information on plant tolerances to temperature, rainfall, floods, drought, etc. to interpret the threat to the species in the hotspot province or protected area.

This is the part of the questionnaire that will change significantly between areas with different climate predictions.

Protection from the extremes of climate are considered based on the habitat where the species is found and includes moderating influences such as the presence of forest cover. Sensitivity to climate change relates to basic biological tolerances. Adaptive capacity covers the biological, reproductive, and behavioral mechanisms that the species may adopt to avoid or manage extremes of climate.

Together with the database for the species and a description of the climate changes predicted, excel spreadsheets were prepared for each species that provide an accessible record of the assessment and the rationale for the scoring. This rationale is important for understanding the assessment, and has been used in the narrative of the profiles for each species.

#### 3.4.3.5 Limitations

There is a shortage of information on the biological characteristics of most NTFP and CWR species. The focus of earlier studies has been on the use of NTFPs, rather than their biology or ecological and climate requirements. For NTFPs and for CWRs, reference has to be made to other species of the same genus that have been studied because they have been domesticated. This has limited the vulnerability assessment, which in many cases has been based upon an expert judgment approach informed by whatever evidence on tolerances can be gathered. Due acknowledgement must be made to the valuable web-based databases, e.g., compiled by FAO, which have provided much of the biological and ecological requirements of the species considered.

The selected NTFP and CWR species are not necessarily representative of the forest ecosystems where they are found. Some are very characteristic of their ecosystem, and some may be keystone species or have very important ecological functions. However, the ecological linkages between species in different assemblages are poorly understood, and it is difficult to draw conclusions beyond those based on individual species biology. The study consists of assessments using information on basic biology and climate tolerances of the selected species. It does not consider the interactions between species and the dependencies of fungi, plants and invertebrates that make up the forest and wetland assemblages where the NTFPs and CWRs are found. Furthermore, the study does not consider the complex effects of climate change on diseases and insect attacks of NTFP plants.

### 3.4.4 NATURAL SYSTEMS - PROTECTED AREAS

#### 3.4.4.1 Selection of protected areas

Protected areas were selected for priority analysis on the basis of the provincial and protected area threat ranking and the representation of differing ecozones.

Projected climate changes in the LMB for the year 2050 led to the identification of eleven hotspot provinces that experience significant changes in temperature, precipitation, and flooding including Chiang Rai and Sakon Nakhon in Thailand; Sekong, Khammouan, and Champasak in Lao PDR; Stung Treng, Mondulkiri and Kangpong Thom in Cambodia; and Ben Tre, Gia Lai and Kien Giang in Vietnam. The five highest-ranked provinces were Chiang Rai, Mondulkiri, Khammouan, Gia Lai, and Kien Giang. Individual LMB protected areas were also subject to ranking according to threats. The hotspot assessment and ranking method is described in section 3.3.

The priority provinces were the point of departure for identifying protected areas for detailed assessment—the individual ranking of protected areas was a second filter. The final selection of protected areas was based on the following criteria:

- Located within priority hotspot provinces;
- Highly-ranked protected areas in terms of percent change in climate conditions to 2050;
- Located within the priority provinces that are representative of one or more ecozone;
- Located within a province that formed part of a protected area cluster or shared a contiguous boundary; and

- Substantial provisioning and servicing function for local communities as part of their farming ecosystem.

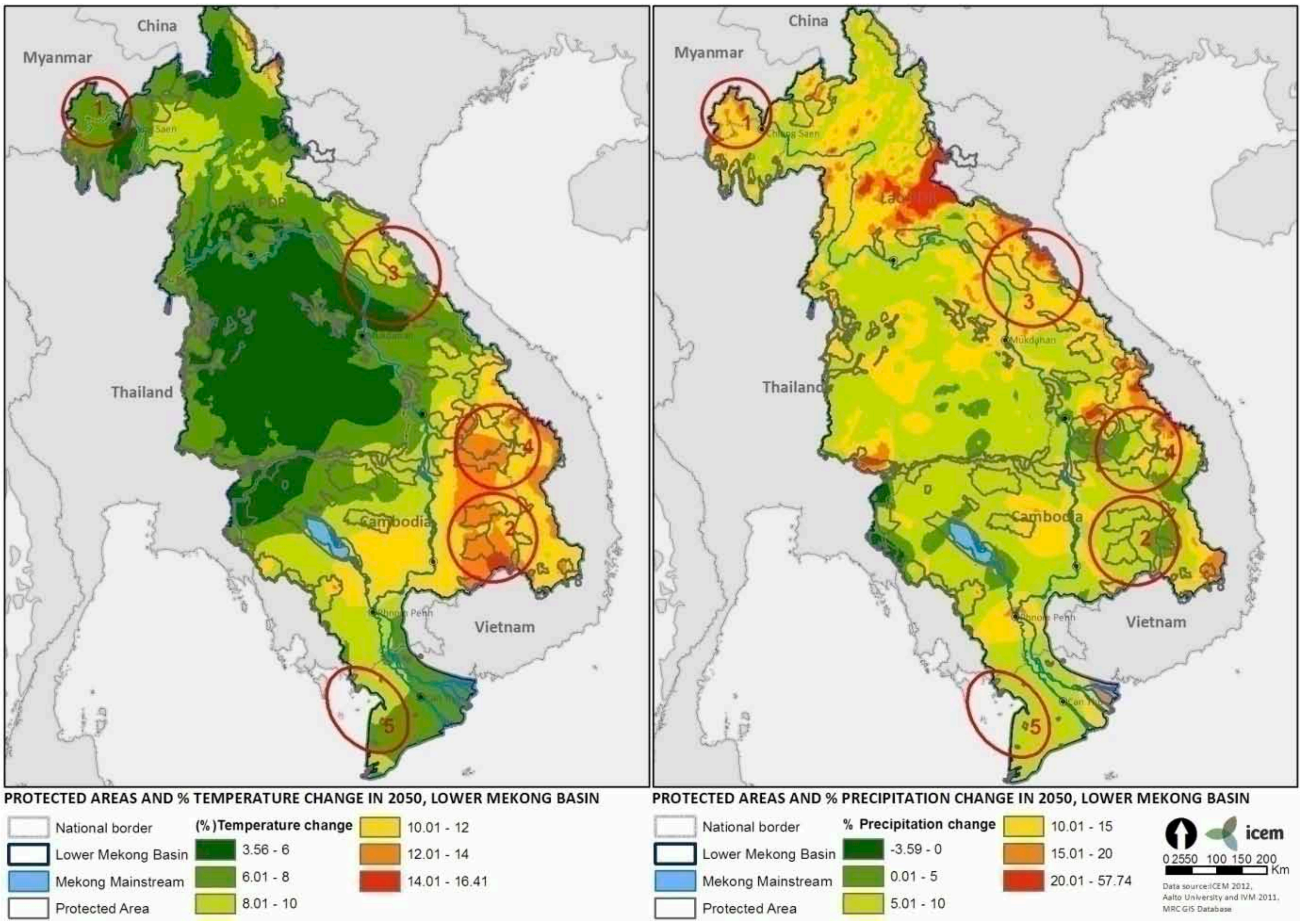
Protected area clusters were chosen in preference to individual protected areas because they represent large areas of each ecozone and allow better demonstration of a range of biological adaptation responses and strategies. Also, protected area clusters have the potential to offer more secure and stable conditions for biodiversity in the face of climate change and other threats—mainly because of their size and diversity in habitats and biogeography. It was not possible to identify clusters in all cases.

The protected areas and ecozones represented by the five priority protected area clusters or individual ones are summarized in Table 13 and Figure 3-22.

**Table 13: Selected protected areas and representative ecozones**

| Province | Country | Protected Area | Ecozone |
|---|---|---|---|
| 1. Chiang Rai | Thailand | ▪ Nong Bong Kai – Non Hunting Area | ▪ Ecozone 12 – Upper floodplain wetland, lake |
| 2. Khammouan | Lao PDR | ▪ Nakai-Nam Theun NBCA<br>▪ Hin Namno<br>▪ Phoun Hin Poun<br>▪ Corridor Nakai – Nam Theun and Phou Hin Poun | ▪ Ecozone 4 – High elevation moist broadleaf forest<br>▪ Ecozone 8 – Low-mid elevation moist broadleaf forest |
| 3. Mondulkiri | Cambodia | ▪ Mondulkiri Protected Forest<br>▪ Phnom Prich Wildlife Sanctuary<br>▪ Lomphat Wildlife Sanctuary<br>▪ Phnom Nam Lyr Wildlife Sanctuary<br>▪ Seima Protected Forest | ▪ Ecozone 6 – Low elevation dry broadleaf forest<br>▪ Ecozone 10 – Mid elevation dry broadleaf forest |
| 4. Gia Lai | Vietnam | ▪ Chu Prong | ▪ Ecozone 6 – Low elevation dry broadleaf forest<br>▪ Ecozone 10 – Mid elevation dry broadleaf forest |
| 5. Kien Giang | Vietnam | ▪ Ha Tien<br>▪ Hon Chong<br>▪ Kien Luong mangrove forest<br>▪ U Minh Thuong National Park | ▪ Ecozone 2 – Delta mangroves and saline water<br>▪ Ecozone 3 – Delta Low lying acidic area swamp forest |

Figure 3-22: Climate change in the Lower Mekong Basin (red circles show hotspot provinces with their protected areas cluster)




Brief baseline profiles for each individual protected area or cluster were prepared and climate change modeling data for each was analyzed for changes in temperature, precipitation, and water availability on an annual and seasonal basis. Key threats to each of the individual protected areas or clusters were identified from this analysis and formed the basis of subsequent vulnerability assessments.

### 3.4.4.2 Ecosystem services approach

The links between natural systems and economies are often described using the concept of ecosystem services, or benefits to human communities originating from the state and quantity of natural capital. The Millennium Ecosystem Assessment defined four categories of ecosystem services that contribute to human well-being, each underpinned by biodiversity (MA 2005). Protected areas provide linkages and support for agricultural systems and livelihoods in the form of these four key categories of services (TEEB 2010); these service categories provide the framework for analysis of climate change impacts on protected areas in this study:

**Provisioning services** relate to the material output from an ecosystem including food, water, and other resources.

- Food: Ecosystems provide the conditions for growing food – both in wild habitats and in managed agro-ecosystems.
- Raw materials: Ecosystems provide a great diversity of materials for construction and fuel.
- Freshwater: Ecosystems provide surface and groundwater.

- Medicinal resources: Many plants are used as traditional medicines and as inputs for the pharmaceutical industry.

**Regulating Services** are provided by ecosystems acting as regulators, e.g., regulating the quality of air and soil or providing flood and disease control.

- Local climate and air quality regulation: Trees provide shade and remove pollutants from the atmosphere. Forests influence rainfall.
- Carbon sequestration and storage: As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.
- Moderation of extreme events: Ecosystems and living organisms create buffers against natural hazards such as floods, storms, and landslides.
- Wastewater treatment: Micro-organisms in soil and in wetlands decompose human and animal waste, as well as many pollutants.
- Erosion prevention and maintenance of soil fertility: Soil erosion is a key factor in the process of land degradation and desertification.
- Pollination: Some 87 out of the 115 leading global food crops depend upon animal pollination, including important cash crops such as cocoa and coffee.
- Biological control: Ecosystems are important for regulating pests and vector borne diseases.

**Habitat or Supporting Services** underpin almost all other services. Ecosystems provide living spaces for plants or animals; they also maintain a diversity of different breeds of plants and animals.

- Habitats for species: Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migrating routes.
- Maintenance of genetic diversity: Genetic diversity distinguishes different breeds and races, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial crops and livestock.

**Cultural Services** include the non-material benefits people obtain from contact with ecosystems. They include aesthetic, spiritual, and psychological benefits.

- Recreation and mental and physical health: The important role of natural landscapes and urban green space for maintaining mental and physical health is increasingly being recognized.
- Tourism: Nature tourism provides considerable economic benefits and is a vital source of income for many countries.
- Aesthetic appreciation and inspiration for culture, art, and design: Language, knowledge, and appreciation of the natural environment have been intimately related throughout human history.
- Spiritual experience and sense of place: Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

Climate change will affect ecosystem services to varying degrees according to impacts on, for example, hydrology and water resources; soil and its structure, composition, and stability; wild terrestrial and aquatic species; and crops and other domesticated species and their requirements.

#### 3.4.4.3 Vulnerability assessment of protected areas

Vulnerability assessments were carried out for selected protected areas—both individual and clustered—within the LMB using the CAM method (ICEM 2010). In this context *climate change* **vulnerability** *refers to the degree to which an ecological system or species is likely to experience harm or benefit as the result of changes in climate*. Each protected area assessment used the CAM method to analyze the threats and consequences of changes in regular and extreme climate for identified key assets or components of a given protected area system. These key aspects or components were drawn from the ecological characteristics of habitats, species, communities, and ecosystem services identified in the protected area baseline profiles.

**Threats** to protected area system components and services were identified through analysis of climate change modeling results, namely changes in temperature, precipitation, water availability, sea level and salinity, and changes in extreme events such as drought, flooding, flash floods, and storms.

The **impact** of these threats on the protected area ecosystem components and services was determined by rating the level of exposure and level of sensitivity from Very Low to Very High. The levels were set using available science-based evidence on species and habitat, supplemented by expert judgment.

The next step in applying the CAM methodology was to determine the adaptive capacity of the system or assets to the impact. A protected area management board with a low adaptive capacity would imply a limited institutional capacity and limited access to technical and financial resources. A natural systems example may vary from a degraded habitat with limited ability to regulate microclimate and regenerate, to a mature forest environment with a high capacity for climate regulation along with high species diversity. The mature forest will have a higher capacity to regenerate following stress compared to the degraded habitat. *A vulnerable ecosystem is one that is highly exposed to changes and extremes in climate and hydrology, is sensitive to those extremes and changes, and has limited ability to withstand or recover from the resulting impacts.*

### 3.4.5 CAPTURE FISHERIES

The capture fisheries **baseline assessment** draws on many studies of fisheries in the Mekong basin and other studies of the effects of climate change on freshwater and marine fisheries in other regions. This information is summarized in the overview section of the capture fisheries baseline report where the main impacts that climate change can have on aquatic species are discussed.

In order to describe the various geographical areas of the capture fisheries system, catchment data were overlaid on the ecozones to indicate which important species were likely to be represented in each zone. Each zone was then described in terms of important fishing areas and habitats; the small-scale and commercial-scale fishing systems; tolerances and life cycle conditions affecting important species; and the trends, threats, and opportunities facing the capture fisheries livelihood sector in general. The ecozone classification enabled a fresh description of the capture fisheries of the Mekong as it added elevation, and therefore temperature range, to the more commonly-used basin subcatchment descriptions.

**The CAM method** was applied to assess capture fisheries vulnerability to climate change in six hotspots, using a framework of questions (in the context of species, ecozone, and type of climate change threat) to identify which components were likely to be most vulnerable. At the heart of the CAM fisheries method is the **Fish Database** developed as part of the baseline assessment and will be discussed in more detail below. From the Fish Database, indicator species representing a range of fish types (e.g., upland, migratory, white, black, estuarine, and exotic[16]) can be used as proxies to visualize what specific climate change threats might mean for the wider group. The choosing of indicator species from the various fish-type groups represents the specific key capture fisheries environments,

[16] This broad classification system, which is based on behavior and water quality tolerance, is far from perfect. Some species classified as upland, for example, only spend part of their life cycle in upland streams. Some white fish are not strongly migratory unlike the general trend identified for this group (other studies have classified these non-migratory fish as grey), and some can live in low DO conditions, e.g., Pangasius, again differing from typical characteristics for the white fish group in general.

i.e., uplands, rivers (migratory white fish), seasonal wetlands (black fish), and tidal rivers and estuaries (estuarine fish). Exotic fish can make unwelcome appearances in any of these environments. In each of the hotspots, the key aquatic habitats were described and their contribution to production and biodiversity. Indicator species for each habitat were then selected and their vulnerability to climate change tested through CAM analysis.

Currently, the ICEM Fish Database holds information on 30 aquatic species from a wide range of Mekong environments, from upland tributaries to delta areas. Many, but not all of these species are commercially important in the Mekong's capture fisheries. Some species, e.g., *Pangasius pangasius* appear as both aquaculture and capture fisheries species. Information on biology, migration, and water quality tolerances has been entered into the database. While the information on commercially cultured fish species is plentiful, far less is known about the biological requirements for many of the capture fish species. Some of this information is crucial to understanding climate change threats. The continuous addition of new information to the Fish Database and verification of the ecological zone checklist would allow for better judgments to be made in future studies and would strengthen the assessment approach.

CAM analysis for key fish species (representing upland, white, black, and estuarine types) were conducted for six of the hotspot provinces (Chiang Rai, Khammouan, Gia Lai, Mondulkiri, Kien Giang and Stung Treng). Typically, three capture fish species were used in the CAM for each hotspot depending on the ecozone. Overall the number of high or very high vulnerabilities for each indicator species in each hotspot provided an impression of the overall vulnerability of each hotspot's overall fisheries vulnerability to climate change. Summaries of each of the hotspot provinces were then made, listing the most vulnerable types of fish and the key parameters underlying this vulnerability. Those summaries provided the basis for identifying adaptation measures.

In addition to the vulnerability assessments in the hotspots, four hypotheses relevant to capture fisheries were examined to see if they were supported by the results from the CAM. The hypotheses tested were that:

- Upland fish would be most vulnerable to climate change;
- Migratory white fish would also be vulnerable to climate change;
- Black fish would be more "climate-proof" than other fish types and so may be expected to increase in the proportion of fish catches, as temperatures increase; and
- Exotic species ranges would be extended through climate change.

Where invasive species in the capture fishery have been assessed, the threat is to the fishery itself, rather than to the invasive species. So, for example if an invasive fish species favored warmer water, then under increasing temperatures this would be seen as a threat to the overall fishery rather than a low impact issue for the invasive species. The CAM is therefore inverted for invasive fish species.

### 3.4.6 AQUACULTURE

A similar methodology was used for the aquaculture baseline assessment, vulnerability analysis, and adaptation planning with the following differences. The ICEM Fish Database holds information on a range of indigenous and exotic aquatic species used in aquaculture. Information on biology and water quality tolerances is generally richer than for capture fisheries species. The main aquaculture species cultured in the Mekong basin have been selected for the Fish Database, some of which are exotic and have the potential to become invasive and affect indigenous aquatic life and habitats.

The aquaculture systems for each ecozone are described in the fisheries baseline report. Some zones, e.g., the Mekong Delta, have well-defined aquaculture systems but in many ecozones the aquaculture systems and species used are less distinct, making comparative analysis difficult.

In most of the provincial hotspots, three cultured fish species were used representing extensive, semi-intensive, and intensive aquaculture systems. As with the capture fisheries CAM, the number of high or very high vulnerabilities for each indicator species and system provided an impression of the overall vulnerability of aquaculture to climate change within each hotspot area.

Two additional hypotheses were examined through use of the CAM methodology on aquaculture:

- Aquaculture would be more vulnerable to climate change scenarios than capture fisheries.
- Intensive aquaculture would be more vulnerable to climate change than semi-intensive or extensive systems even though the more intensive systems would have greater adaptive capacity in the form of technology and management.

### 3.4.7 SOCIO-ECONOMICS (HEALTH AND RURAL INFRASTRUCTURE)

The five hotspot provinces were the focus of in-depth analysis for the purpose of assessing the climate change vulnerability of the health and rural infrastructure sectors. Vulnerability and adaptation assessments were conducted for each livelihood zone within each province with the results upscaled to overall livelihood zone trends. Table 14 depicts the coverage of the provinces by livelihood zone.

**Table 14: Distribution of livelihood zones across hotspot provinces**

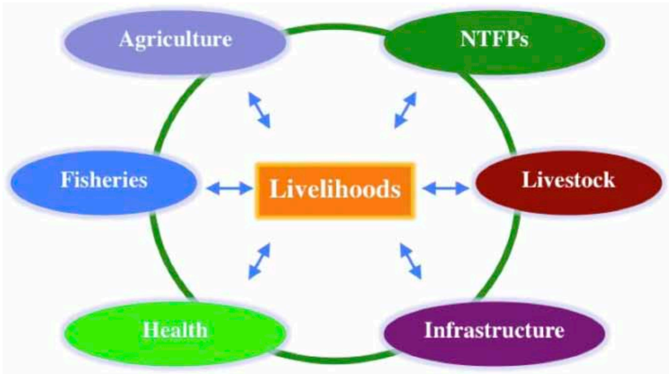
| Livelihood zone | Mondulkiri | Gia Lai | Khammouan | Chiang Rai | Kien Giang |
|---|---|---|---|---|---|
| 1. *Forested uplands* | 23% | - | 17% | - | - |
| 2. *Intensively-used uplands* | - | 32% | | 62% | - |
| 3. *Lowland plains and plateaus* | 77% | 68% | 78% | 21% | - |
| 4. *Floodplain* | - | - | 5% | 17% | - |
| 5. *Delta* | - | - | - | - | 100% |

#### 3.4.7.1 Socio-economic analysis

As described above, the study involved five theme groups addressing different systems: agriculture, fisheries, natural systems, livestock, and social and economic systems. The social and economic assessment focuses on the direct impacts of climate change on the components of livelihood systems that are not captured by the climate change vulnerability assessments performed by the other theme groups. Two critical sectors for community resilience remain outstanding: health and infrastructure.

The interaction of these various systems within a representative rural household in the LMB is depicted in Figure 3-23. Another task of the socio-economic theme group was to aggregate the direct and indirect impacts on livelihood systems and consider the various inter-linkages between sectors.

Figure 3-23: The structure of the livelihood system in a representative rural household in the LMB




The **livelihood system** is the foundation of the socio-economic analysis in this project. Beyond the direct, immediate impact on livelihoods, there are indirect factors to consider over the longer term. For example, lower rice yields due to climate change may: (i) lower incomes, reduce food security, and, potentially lower household health, (ii) increase dependence on capture fisheries and NTFPs for food, and (iii) decrease the level of household and community income available to spend on asset improvements or repairs.

In this report the *livelihood systems* and *livelihood zones* provide the conceptual basis for the analysis of integrated effects of climate change and for integrated adaptation responses. The objective is to present a broader picture at the basin level of the key linkages between sectors in a way that informs and guides local-level studies and actions to be undertaken in subsequent USAID Mekong ARCC tasks.

### 3.4.7.2 Health

Human health is the foundation of productivity in all livelihood activities. Poor health limits the capacity of individuals to farm, fish, gather NTFPs, or attend to livestock. Adequate health ensures the nutritional benefits of food consumption are realized - an important but often forgotten component of food security. The inability of an individual to work due to poor health reduces household income and therefore impacts on the food security of the entire household and, potentially, the broader community.

In analyzing health, this study draws from four classes of climate change impacts (WHO/WMO 2012, McMichael et al. 2006): (i) infections, including malaria, diarrhea, meningitis, and dengue fever; (ii) emergencies, including floods and cyclones, drought, and airborne dispersion of hazardous materials; (iii) environmental conditions, including heat stress, UV radiation, pollens, and air pollution; and (iv) indirect impacts on crop yields and relocations due to flooding and drought.

Much research is required into how human health is likely to be affected in particular areas of the LMB. Given the lack of detailed local scientific knowledge, this study draws on international experience to identify a number of key health issues most likely to arise in the LMB (WHO/WMO 2012, McMichael et al. 2006, Portier et al. 2012, MRC 2010, World Bank 2011a, 2011b, 2011c). Those issues are:

- **Heat stress:** The impacts on human health of exposure to high temperatures. Impacts include: exhaustion, fainting, strokes, as well exacerbation of existing conditions. Sherwood et al. (2010) identify prolonged exposure to 35°C as a key threshold for heat stress.

- **Water-borne disease:** Diseases that are caused by microorganisms and other contaminants found in drinking water and other water that humans use. Diarrheal diseases are the most common water-borne diseases and a major cause of illness and death in the LMB at present. There is a clear existing link between flooding and water-borne disease. Climate change-driven increases in precipitation and flooding will disrupt the functioning and safety of water sources (e.g., water bores becoming contaminated with surface floodwaters). Moreover, poor water availability in such instances increases the risk of oral-fecal contamination.
- **Vector-borne disease:** Diseases such as malaria and dengue fever (both of which are present in the LMB) that are spread by mosquitoes, ticks, and other disease vectors. It is widely acknowledged that higher levels of precipitation and temperature influence the distribution of vector-borne disease by improving the breeding habitat of disease vectors.
- **Injury, death, or other health issues caused by extreme weather or other events related to climate change:** Violent events such as landslides and floods have the potential to cause serious injury or death. Moreover, the persistence of extreme weather-related phenomena, such as flooding, restricts access to forest resources that support food security and human health. Forced relocation of rural communities to areas of higher population density increases the risk of disease transmission.



#### 3.4.7.3 Rural infrastructure

*Rural infrastructure is the physical, stationary infrastructure that enables rural households and communities to pursue and benefit from livelihood activities.* For example: roads and bridges that facilitate sales and purchases at district markets; covered groundwater bores and health facilities that sustain health; and housing and other buildings that provide shelter for people and their assets. Damage or lack of access to such infrastructure can have long-term impacts on poverty and food security.

Past experience in the LMB demonstrates the extensive and serious effects of extreme climate events on local infrastructure; these effects include damaging and destroying facilities essential for local economies and livelihoods. Projected increased intensity and frequency of extreme events should be taken into account in the planning, maintenance, and adjustment of those strategic assets. This study considered roads, bridges, water supply infrastructure (such as groundwater bores, irrigation canals, and farm dams), housing, grain storage, and other household buildings, and health centers and other municipal or communal buildings, such as market-places.

#### 3.4.7.4 Threats and assessment criteria

The social and economic assessment did not consider the full range of threats covered by other sectors. In particular, the water availability index was not considered. The reason for that omission is, despite the potential importance of soil water availability for the functioning of groundwater wells, there was insufficient information available to determine the impact of changed soil water availability on groundwater hydrology. An additional threat was considered: landslides. This inclusion is due to the importance of these events to the integrity of infrastructure in sloping areas, as well as their devastating health impacts. The range of considered climate threats included: temperature, precipitation, drought, floods, flash floods, landslides, and in deltaic areas sea-level rise and salinity.

The criteria used to determine the main components of the CAM vulnerability assessment and their definitions are shown in Table 15.

**Table 15: CAM vulnerability criteria for health and infrastructure**

| Exposure | Sensitivity | Adaptive capacity |
| --- | --- | --- |
| **Location** of people/assets in relation to the threat | **Poverty** – poverty rate of the population based upon the national poverty line. Measured by an income based or expenditure based poverty line depending on country. | **Assets** – household assets such as land/housing, livestock, other usufruct rights (such as irrigation canals) and other capital assets (e.g., boats, machinery). |
| **Severity** of threat | **Food insecurity** – availability of an adequate quantity and quality of food. Indicated by child malnutrition rates. | **Education/skills** – literacy rates and educational attendance. Also informed by qualitative measures of the quality of education programs. |
| **Duration** of threat | **Human health** – overall level of morbidity and early mortality in the community. Indicated by infant mortality rates and life expectancy. | **Physical infrastructure** – access to key infrastructure and amenities, such as roads, safe drinking water and sanitation supply, and electricity. |
| | **Strength of key infrastructure** – the capacity of infrastructure, such as roads and bridges, to withstand weather-related stress. Measured by the quality of building materials and design, where information is available. | **Access to markets** – Distance and access to transport to markets throughout the year. Percentage of households with access to credit. |
| | **Demographic composition** – communities with a high number of children or elderly who are not engaged in productive activities or are vulnerable to disease are deemed to be more sensitive. This may be indicated by the dependency ratio. Another component is the ethnicity of a community or household; minorities often have less access to social services. | |

In addition to the severity and duration of a particular climate change threat, the location of people and their assets is a contributing factor to exposure. For example, communities living in a floodplain are more exposed to large-scale floods than those living in sloping upland areas who may be more threatened by flash floods.

The five sensitivity criteria are related to the degree to which human health is affected by climate-related events, such as disease outbreaks. The accessibility of roads during a multi-day flood event will critically determine the loss of food and clean water access. Demographic composition is also important: a higher proportion of vulnerable groups within a household or community, such as the sick, the elderly, and the poor, will amplify negative impacts. For infrastructure, the strength of key infrastructure is the most relevant criteria; however, the level of poverty, human health, and food insecurity are also indicative of the resources and supportive infrastructure available to communities.

The adaptive capacity of households and communities is a function of: the assets available (i.e., land, machinery, livestock, natural resources, etc.) that can be used or sold to respond to an adverse shock; education attainment and skills that can be deployed to adapt new techniques or behaviors in a changing environment; the availability of physical infrastructure to facilitate livelihood security (i.e., bridges and roads); access to markets, both in a physical sense (i.e., distance and transport to market to sell and purchase goods and services) and a financial sense (i.e., credit markets to finance investment).

# 4 CLIMATE AND HYDROLOGY PROJECTIONS

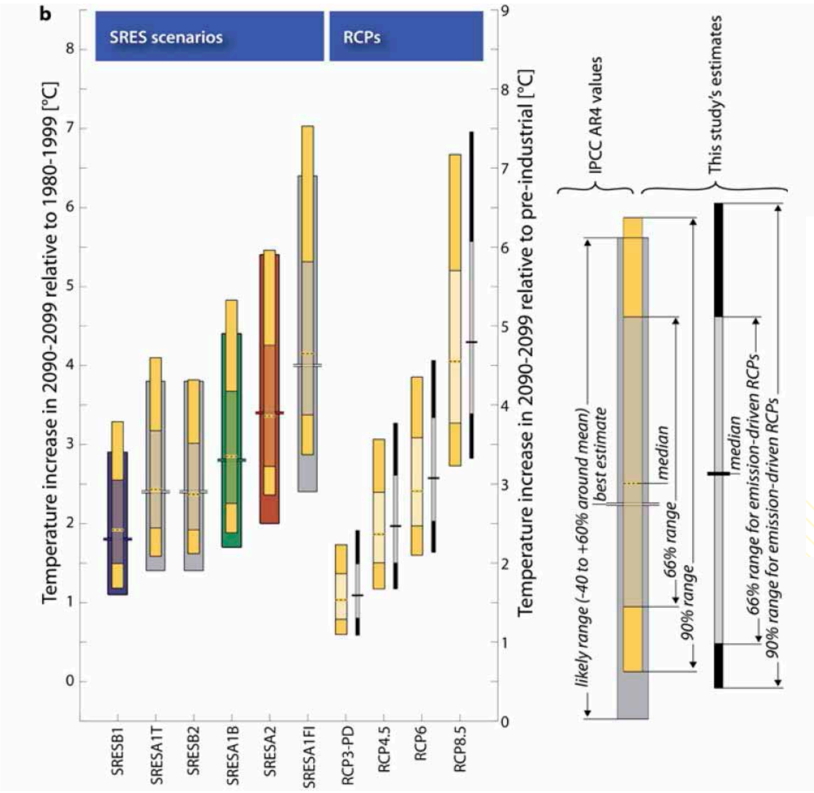
## 4.1 LONG-TERM TRENDS IN MEKONG HYDROCLIMATE

**Compared to preindustrial times, mean global surface temperature has increased by 0.8°C** (IPCC 2007; Jones et al. 2012). While there are many natural factors contributing to changes in surface temperatures, such as ENSO events, volcanic aerosol effects, and variability in solar radiation, there is clear evidence that the rates of warming in the last century are the highest for any in the last 1,000 years and that natural forcings alone cannot explain the warming shift manifest in observations (IPCC 2007; World Bank 2012, Foster et al. 2011; Stott et al. 2000).

**Under A1b—a moderate emissions scenario and the scenario used in this study—global increases in surface temperature are likely to exceed 3°C by the end of this century**. IPCC Assessment Report Four (AR4) concludes that by 2100 global temperatures will increase by 1.6°C to 6.9°C above pre-industrial temperatures (Figure 4-1), with about half of this uncertainty due to variability in future GHG emissions forcings and half related to uncertainty of how the complex, multi-faceted climate system will respond to these GHG forcings (World Bank 2012). In the Fifth Assessment Report due for release in 2013, the SRES scenarios will be replaced by new Representative Concentration Pathways (RCPs)[17]. Figure 4-2 compares projection of future surface temperatures using SRES scenarios and RCPs, with the variability between the scenarios being comparable. In the 13 years since the IPCC SRES was released, actual observed emissions have equaled or exceeded even the most extreme of the SRES scenarios, reducing confidence in the lower estimates for future temperature change (Figure 4-2).

[17] RCPs are new, fully integrated scenarios that represent a complete package of socioeconomic, emissions, and climate projections. RCPs provide data on possible development trajectories for the main forcing agents of climate change that is consistent with current scenario literature. The forcing agents include GHG and air pollutant emissions and landuse. The information can be used for analysis by both climate models and integrated assessment models (Vuuren et al 2011).

**Figure 4-1: (LEFT) Probabilistic estimates of future temperature increases using IPCC SRES and RCP scenarios;** *(Source: Rogelji et al. 2012 cited in World Bank 2012);* **(RIGHT) Comparison of actual $CO_2$ emissions with IPCC scenarios:** *actual emissions have been equaling or exceeding the most extreme emissions scenario since 2003 (Source: GTZ 2009)*



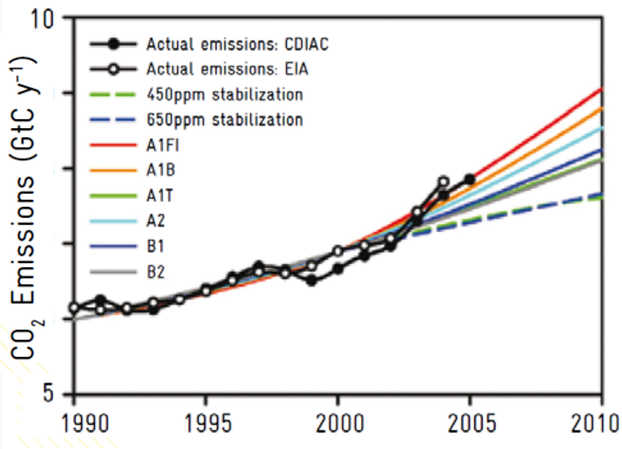
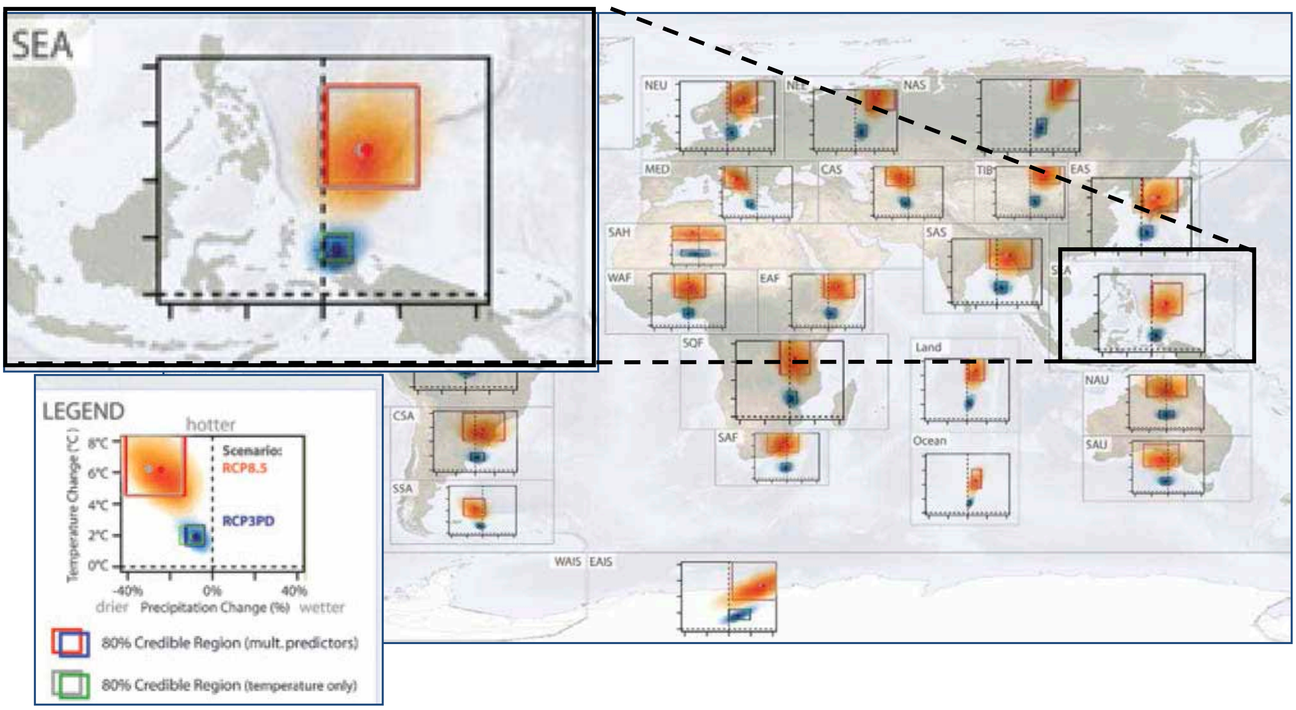




**Figure 4-2: Spatial variability in climate change projections for 2100 for a low RCP (blue) and high RCP (orange):** Horizontal axis shows % change in annual precipitation, vertical axis shows temperature increase in °C *(Source: World Bank 2012)*

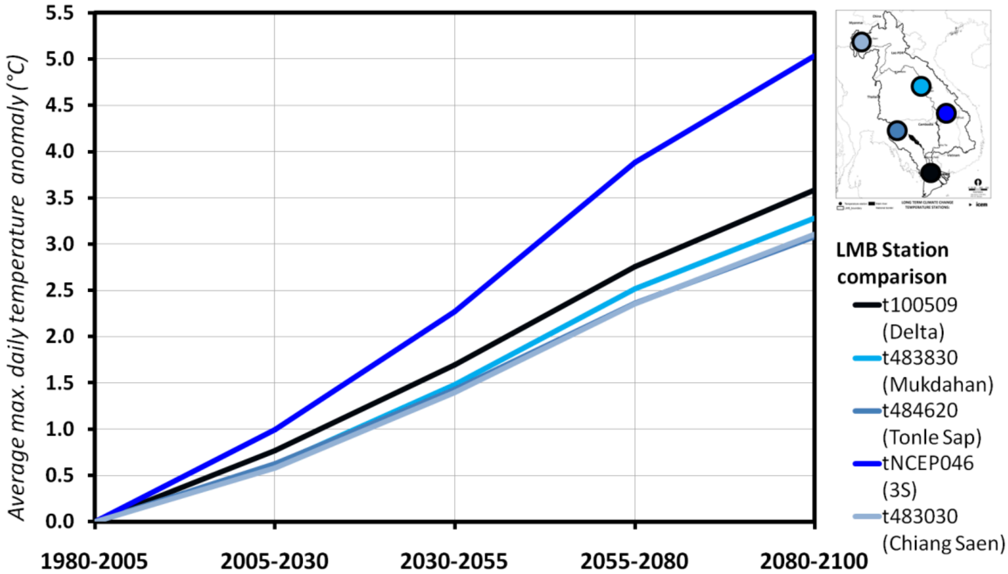


**Climate Change projections vary in space and time.** Globally, increases in temperatures are more pronounced in higher latitudes, while changes in precipitation are much more varied and with weaker directional signals (Figure 4-2). In some regions (Saharan Africa, West Africa, Australia and the Amazon region), there is only weak directionality in precipitation trends, while throughout Asia, there is generally a consistent signal of increasing precipitation in both high and low emissions scenarios (Figure 4-2). Due to lag effects in the response of the climate system to $CO_2$ forcings, variability between emission scenarios becomes pronounced after 2050. In Southeast Asia global projections indicate temperature increases of 2°C to 4°C are likely, with precipitation increasing by up to 20% (Figure 4-2).

**In the LMB, temperature increases are expected to reach an average 3°C to 5°C by the end of the century;** however some pockets of the basin are predicted to experience much larger increases**.** Downscaled temperature data for five stations have been used to assess in more detail long-term signals in average maximum daily temperature based on six GCMs (Figures 4-3). Stations were chosen in Northern Thailand (near Chiang Saen), central LMB (near Mukdahan), the 3S basin of Eastern Cambodia,[18] upland areas of the Tonle Sap basin in Western Cambodia and in the central Mekong Delta (near Can Tho).

**Rates of change in temperature are highest in the 3S catchments of eastern Cambodia and in the Mekong Delta of Vietnam and Cambodia, where increases of 2°C to 3°C can be reached before 2050 and up to 5°C by the end of the century**.

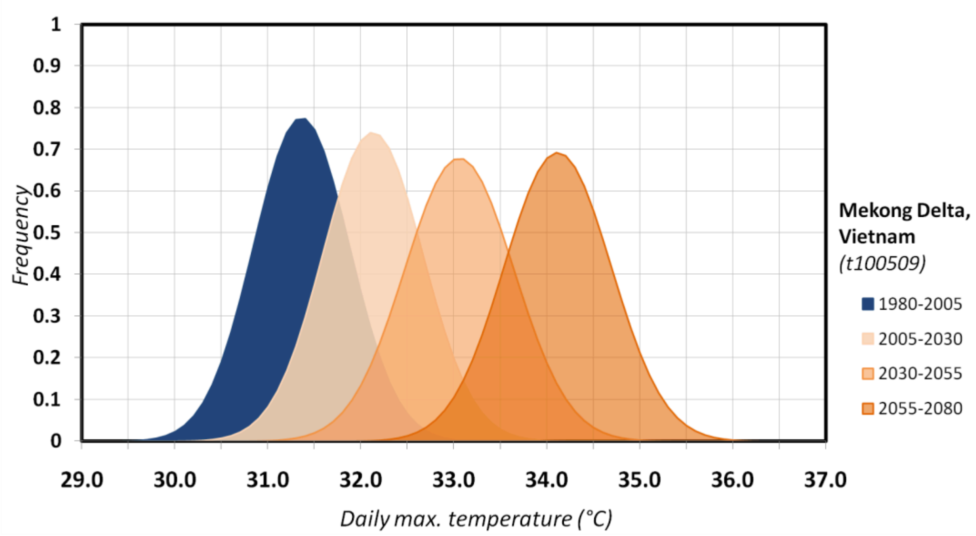
**Figure 4-3: Climate shifts in the Lower Mekong Basin:** *long-term warming signal in daily maximum temperatures at five stations based on the average change from six GCMs and IPCC SRES A1b*




**Throughout the majority of the basin, increases in temperature will result in fundamental shifts in the temperature regime**, with the region frequently experiencing warmer temperatures never reached under baseline conditions (Figure 4-4). In the medium and long term, temperature regimes are also becoming more variable than under baseline conditions (e.g., Figure 4-4).

[18] "3S" refers to the three transboundary river basins of Sesan, Srepok and Sekong which rise in Lao PDR and Vietnam and join the Mekong River in Cambodia.

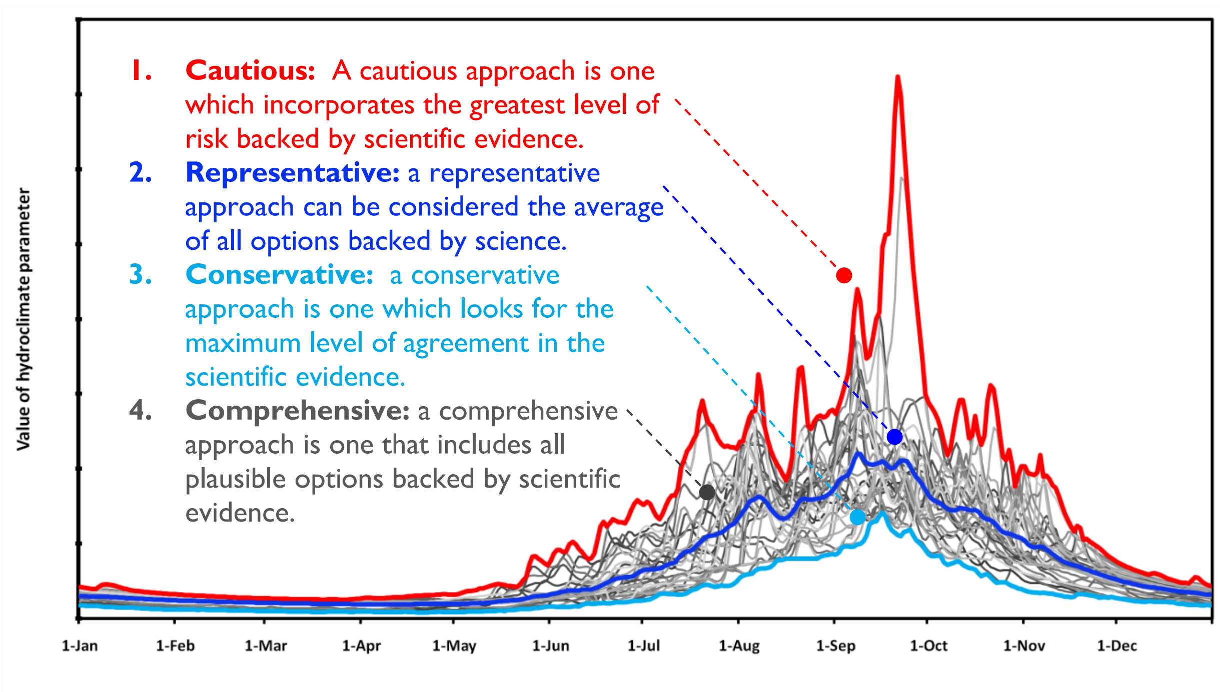
**Figure 4-4: Long-term changes in variability of Mekong temperatures**




## 4.2 COMPARISON OF GCMS

**Climate Change threat assessments culminate in the production of very large databases of information, which need to be consolidated in order to be useful for vulnerability assessments**. In this study a single scenario (A1B) multi-model ensemble (six GCMs) was used to establish climate change threat. This means that in the order of 650 years of daily data was generated for 30 hydroclimate parameters covering some 159,000 grid cells. Presenting this information to sector assessment teams required the team hydrologists to consolidate this information into projections which focused on the trend signal and the range in results.

**Figure 4-5: Reconciling variability in threat projections using cautious (red), representative (blue), conservative (aqua) and comprehensive (grey) approaches**



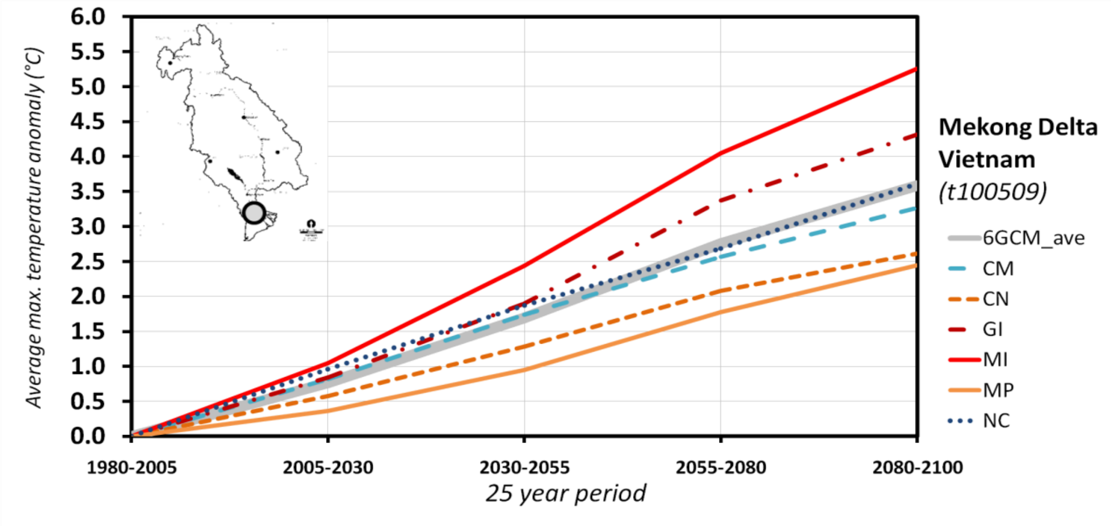
There are a number of options for reconciling the results of the six GCMs, depending on the study's acceptable level of risk and confidence in the climate modeling (Figure 4-5). A cautious approach may use the highest results whereas a conservative approach may use the lower level of GCM results. A representative approach would use the average of GCM results and a comprehensive approach would take into account all the results.

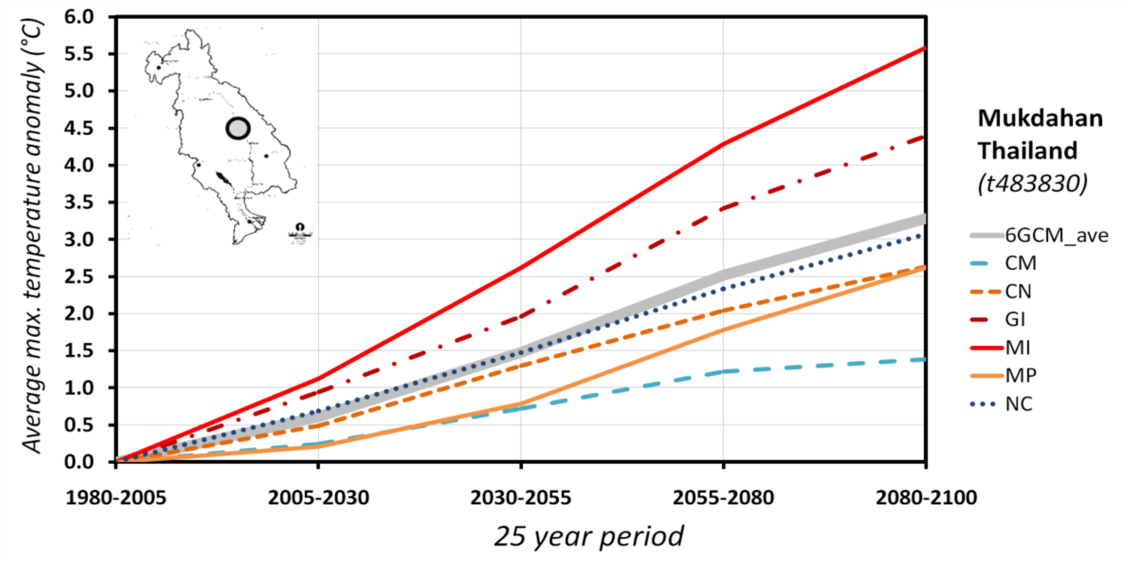
**The study adopts a representative approach with the majority of the findings from the climate change threat assessment based on the averages between the six GCM projections** (Figure 4-5). While this makes the threats more manageable for sector specialists it does have the potential to mask variability in projections. The purpose of this section is therefore to understand the spatio-temporal variability between GCMs outputs, through the consideration of long-term inter-annual variability, seasonal variability within typical years as well as how GCM outputs vary based on location in the basin.

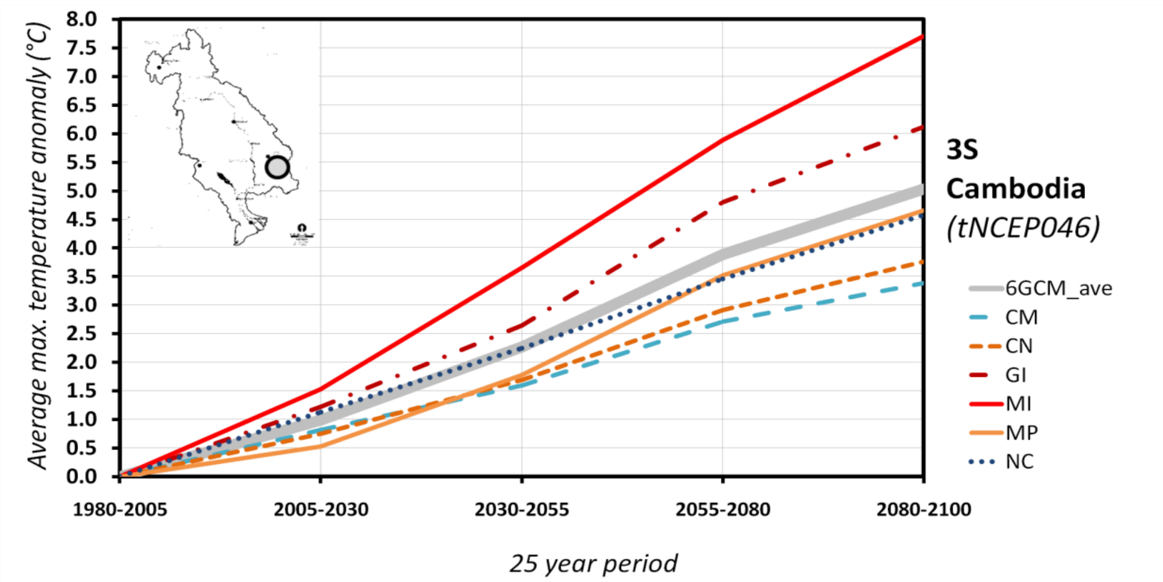
### 4.2.1 LONG-TERM INTER-ANNUAL COMPARISON

**Variability between GCM results increases with time, reaching 3.5°C by the middle of the century and more than 4°C by the end of the century** (Figure 4-6). This variability is the result of how each of the different GCMs are set up and how well the inherent assumptions and equations governing physical climate processes simulate the hydroclimate processes driving the Mekong hydroclimate. The highest projections arise from the GCM Miroc3.2 hires. This model has already been identified as over projecting temperature change due to how the model parameterized cloud dynamics and has recently been revised by model developers (Watanbe et al. 2010). The source of lower estimates varies throughout the basin but typically arises from MP or CM outputs (Figure 4-6).

**Figure 4-6: GCM variability for long-term trends in temperature change in the LMB:** *the set up and assumptions inherent in each GCM model architecture result in variation in the long-term signal*




4 CLIMATE AND HYDROLOGY PROJECTIONS

### 4.2.2 INTER-ANNUAL COMPARISON FOR 2050 TIME SLICE

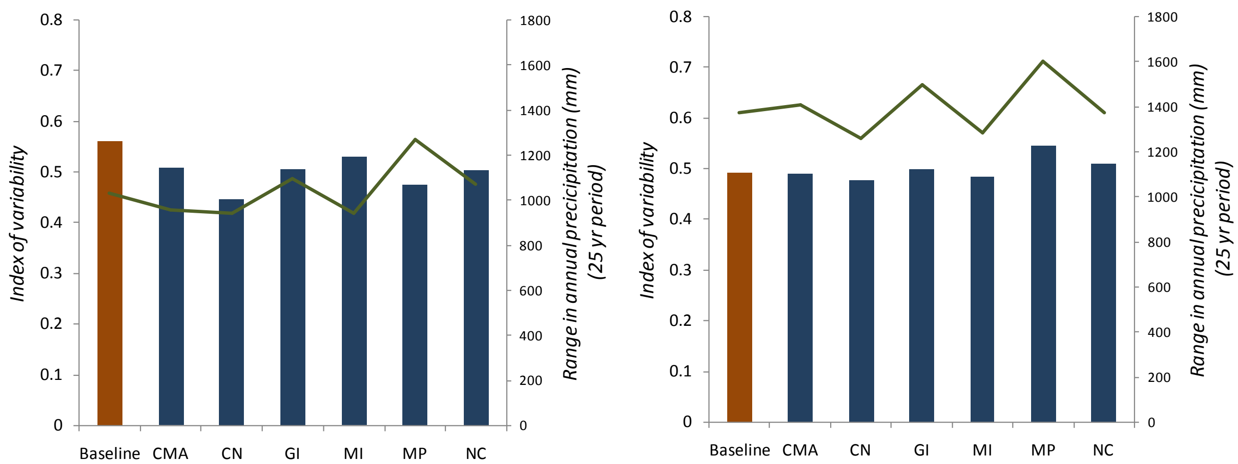
To assess the inter-annual variability in the results of the six GCMs over the study time slice (2045–2069), the team analyzed results for two temperature and two precipitation sites in the basin. Ca Mau (Vietnam) and Champasak (Lao PDR) Provinces were chosen as the sites for precipitation comparison; they represent areas of medium precipitation change and different seasonal patterns. Savannakhet (Lao PDR) and Stung Treng (Cambodia) Provinces were chosen as sites for comparison of GCM maximum temperature; they represent areas of high (Stung Treng) and medium (Savannakhet) changes in temperature.

#### 4.2.2.1 Precipitation

**In the provinces of Ca Mau and Champasak there will be a negligible difference in the inter-annual variability of precipitation.** In Ca Mau the inter-annual precipitation variability index[19] of the six GCMs differs by only 0.08 and on average shows a negligible decrease in inter-annual precipitation variability compared to the baseline (Figure 4-7). This equates to an average 15 mm reduction in the range of annual precipitation. In Champasak the inter-annual precipitation variability index for the GCMs differs by only 0.07 and shows a negligible increase compared to the baseline—or an average 30 mm increase in the range of annual precipitation over the 25 year period.

**Figure 4-7: Comparison of the inter-annual variability in GCM precipitation:** *results for Ca Mau and Champasak province. Bars show the index of variability and line shows the inter-annual range in precipitation over a 25 year period*

**a) Ca Mau province site** **b) Champasak province site**




#### 4.2.2.2 Temperature

**In the provinces of Savannakhet and Stung Treng there will be a negligible change in the inter-annual variability of seasonal average temperatures.** In both provinces most GCMs show that both seasons will experience a slight decrease in the inter-annual range of temperatures (Figure 4-8).[20] In Savannakhet over a 25 year period, the inter-annual range in wet season temperatures will decrease by around 0.7°C while the dry season range will increase by around 0.5°C. In Stung Treng the results are slightly more substantial during the dry season for which the

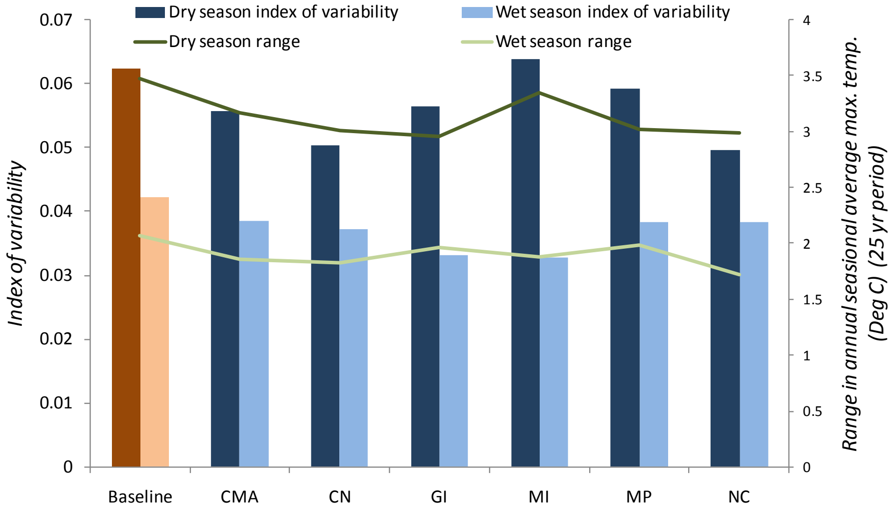
[19] Inter-annual variability has been assessed using a measure commonly used in the literature: the variability index, which is the spread of the 90th and 10th percentiles divided by the median rainfall or temperature

[20] The GCM Miroc3.2 hires is the only GCM that shows a slight increase in dry season temperature variability. The model has been shown to overproject temperature changes from February to May and has recently been revised by model developers (Watanbe et al 2010)

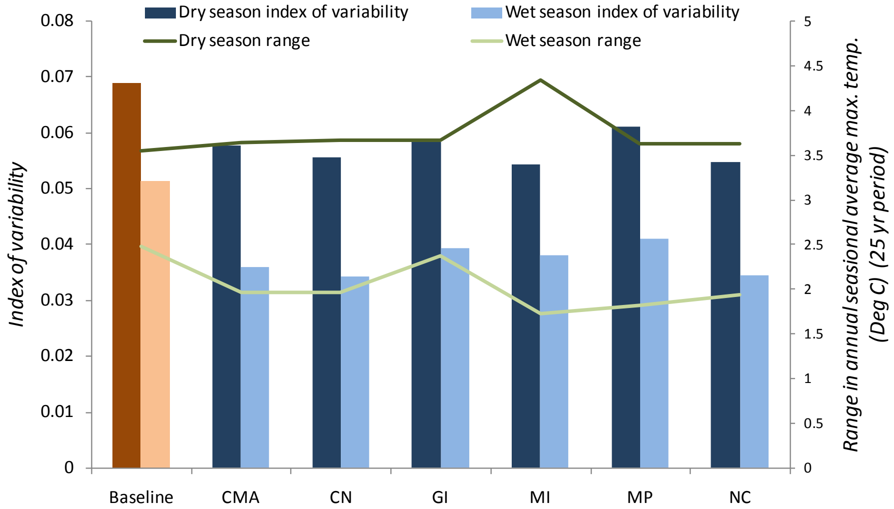
seasonal inter-annual range will increase by around 1.7°C.  The range in wet season temperatures will decrease by around 0.6°C.

**Figure 4-8: Inter-annual comparison of GCM maximum temperature:** *results for a) Savannakhet and b) Stung Treng provinces.  Bars show the index of variability and line shows the inter-annual range in seasonal average temperature over a 25 year period*

**a) Savannakhet province site**




**b) Stung Treng province site**




### 4.2.3 INTRA-ANNUAL COMPARISON FOR 2050 TIME SLICE

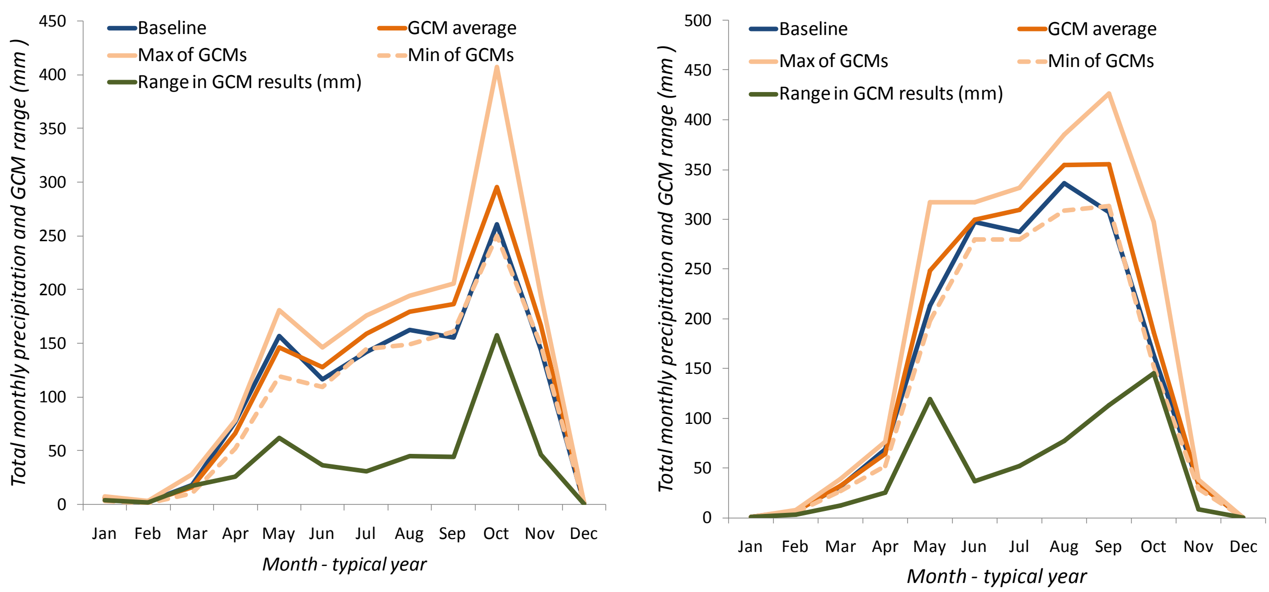
To assess the *intra*-annual variability in the results of the six GCMs the study analyzed time series of results for the same two temperature and two precipitation sites in the basin that were discussed above in regard to *inter*-annual variability—Ca Mau (Vietnam) and Champasak (Lao PDR) for precipitation; and Savannakhet (Lao PDR) and Stung Treng (Cambodia) for temperature.

#### 4.2.3.1 Precipitation

**There is a strong correlation between both the size of the projected change in monthly rainfall and the range in GCM precipitation results and cumulative monthly rainfall totals** (Figure 4-9). During the peak rainfall months of the wet season, when projected changes in precipitation are highest, the range in GCM results is greater. During the dry season, when monthly rainfall is lower and projected changes are lower, the absolute range in GCM results is lower.

**Figure 4-9: Intra-annual comparison of the range in GCM precipitation:** *results for a) Ca Mau and b) Champasak provinces*

**a) Ca Mau province site** **b) Champasak province site**




**Variability is greatest during the onset of the monsoon and the onset of the cyclone season**, suggesting that models have some uncertainty in simulating these two important hydroclimate phenomena.

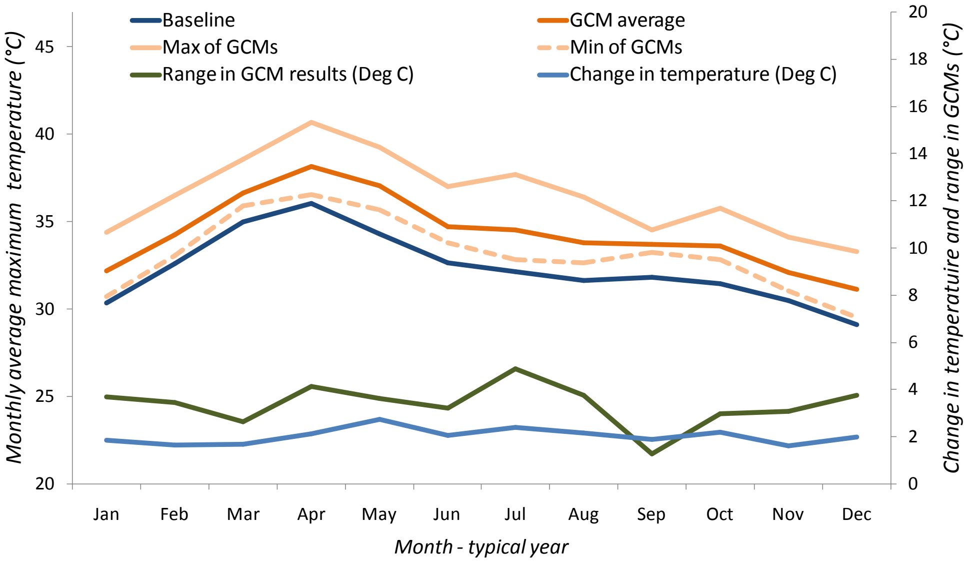
#### 4.2.3.2 Temperature

**A similar pattern is noticed in the provinces of Savannakhet and Stung Treng where there is a strong correlation between the size of the projected increase in maximum temperatures and the range in GCM results.** For months where larger changes in maximum temperatures are projected there is a larger variability between the GCM results (Figure 4-10).

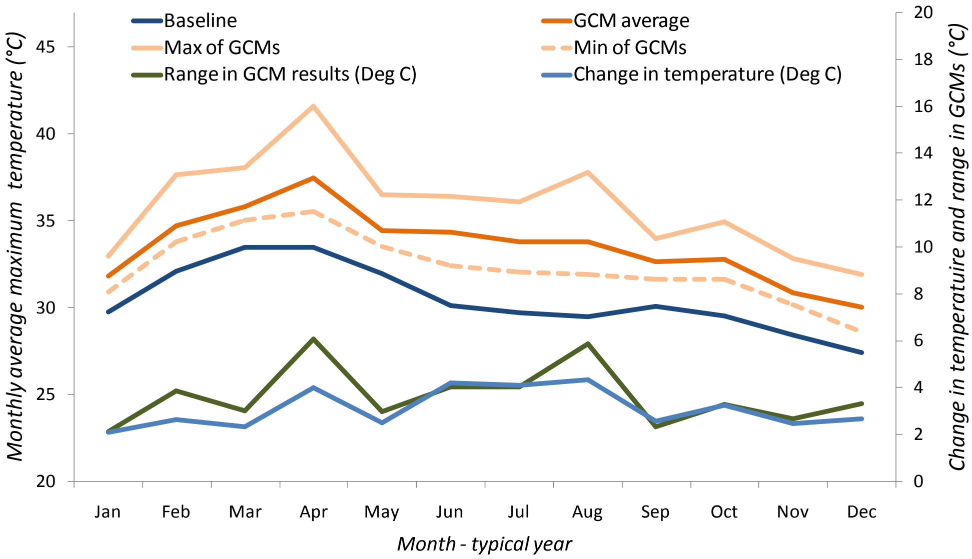
The clear correlation between the size of the projected changes and the range of GCM results indicates that the variability between GCMs is a function of how the GCMs are set up and how they resolve the physical processes in the basin.

**Figure 4-10: Intra-annual comparison of GCM maximum temperature:** *results for a) Savannakhet and b) Stung Treng provinces*

**a) Savannakhet province site**




**b) Stung Treng province site**




### 4.2.4 SPATIAL COMPARSON FOR 2050 TIME SLICE

**Variability in projected changes in seasonal precipitation between the six GCMs is greatest in the wet season, in the low/mid-elevation zones of the 3S basins, the Vientiane plain and northern Lao PDR** (Figure 4-11). During the dry season the GCM results vary between 31–300 mm whereas during the wet season the results vary between 31–500 mm.

**For seasonal maximum temperatures, the range in GCM results is higher in the dry season, in the Cambodian floodplain, and in the mid-elevation zones of the 3S basins** (Figure 4-12).The variability in GCM results for maximum temperatures during the wet season is 1.5°C to 4°C. In the dry season the variability is 1.9°C to 4.5°C. For both seasons the area of greatest GCM variability correlates with areas of highest projected changes in temperature—the southern part of the Cambodian floodplains and in lower sections of the 3S basin reaching towards the Vietnamese highlands.

**Figure 4-11: Variability in GCM results for seasonal precipitation**

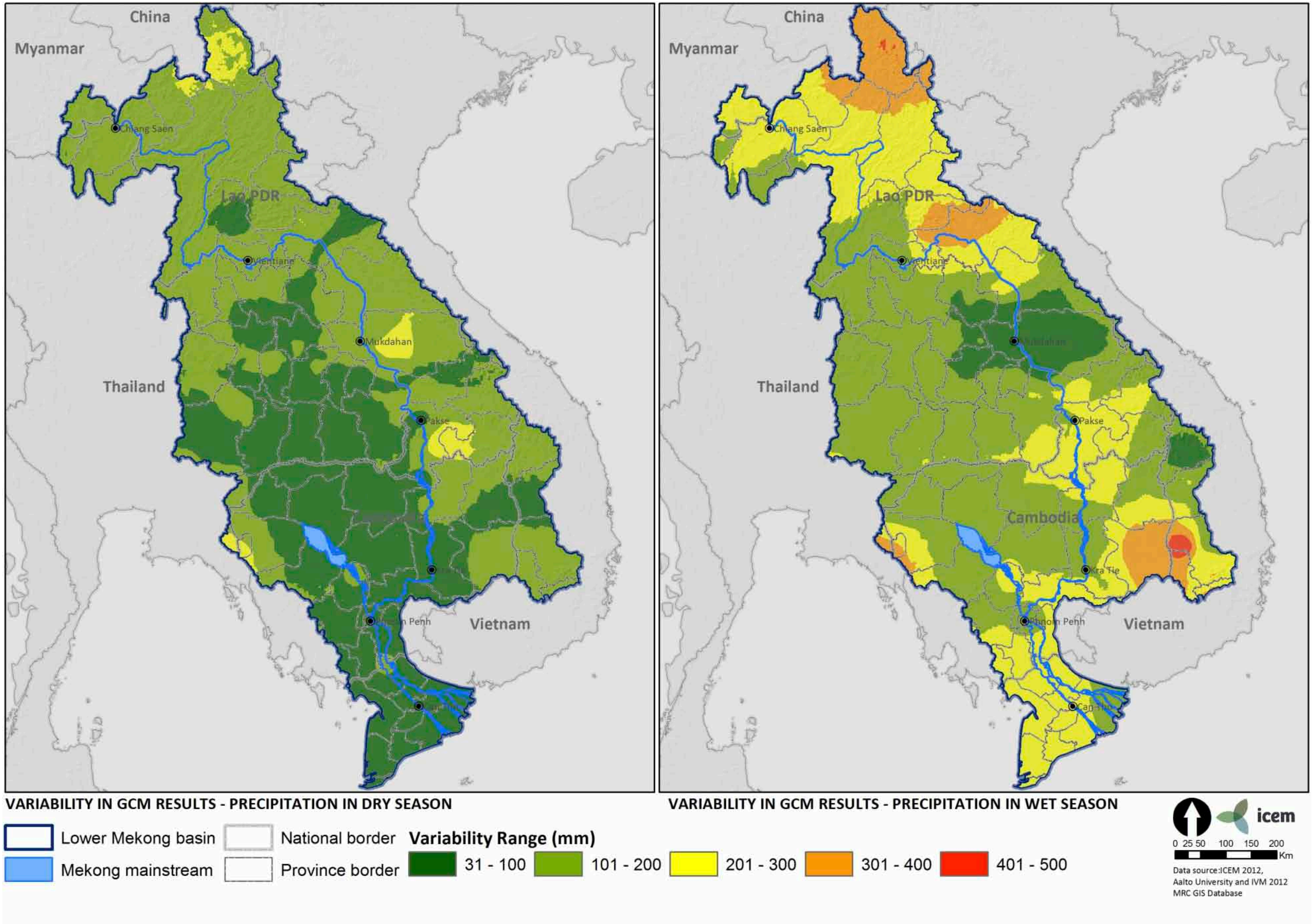
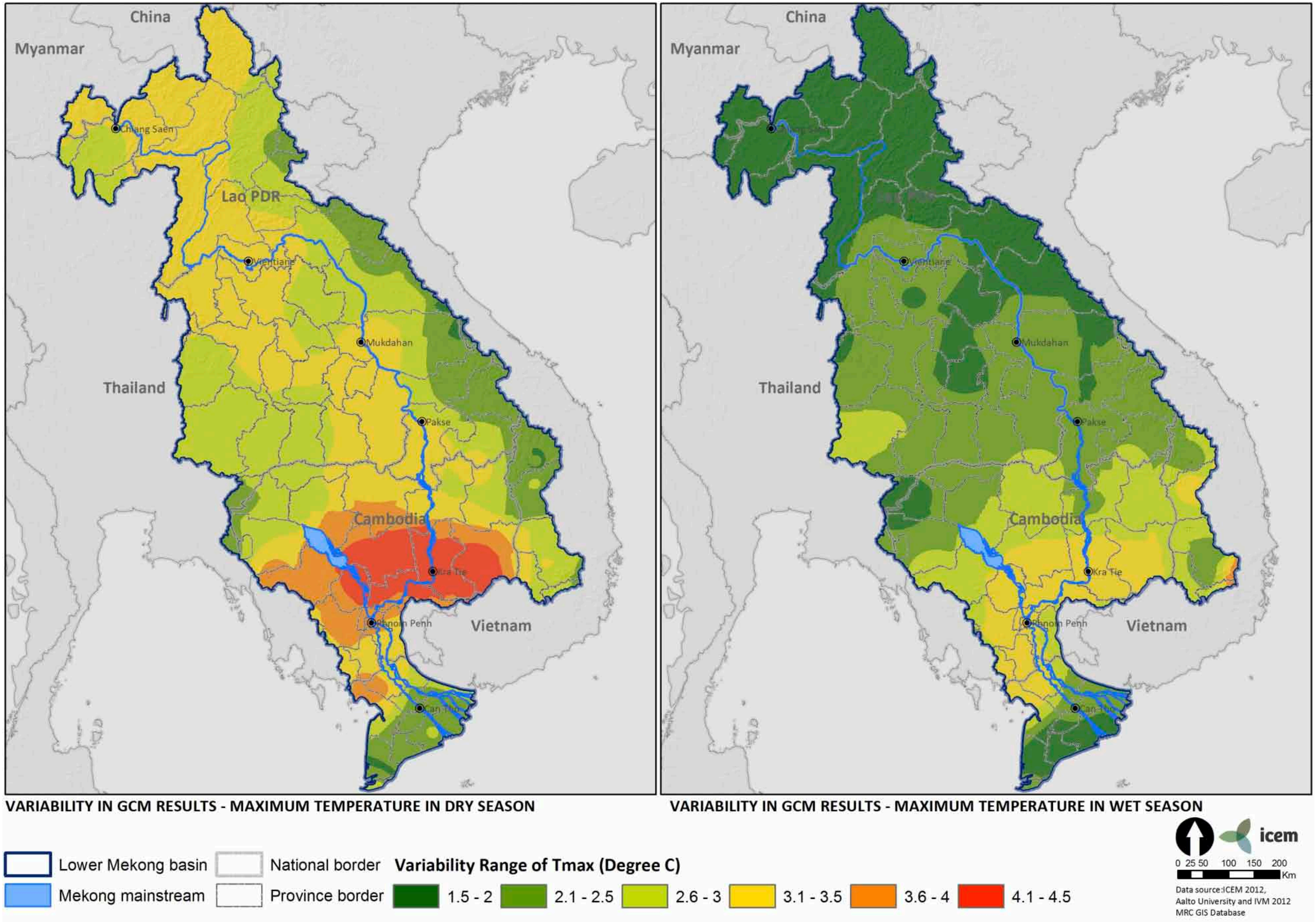


Figure 4-12: Variability in GCM results for seasonal maximum temperature



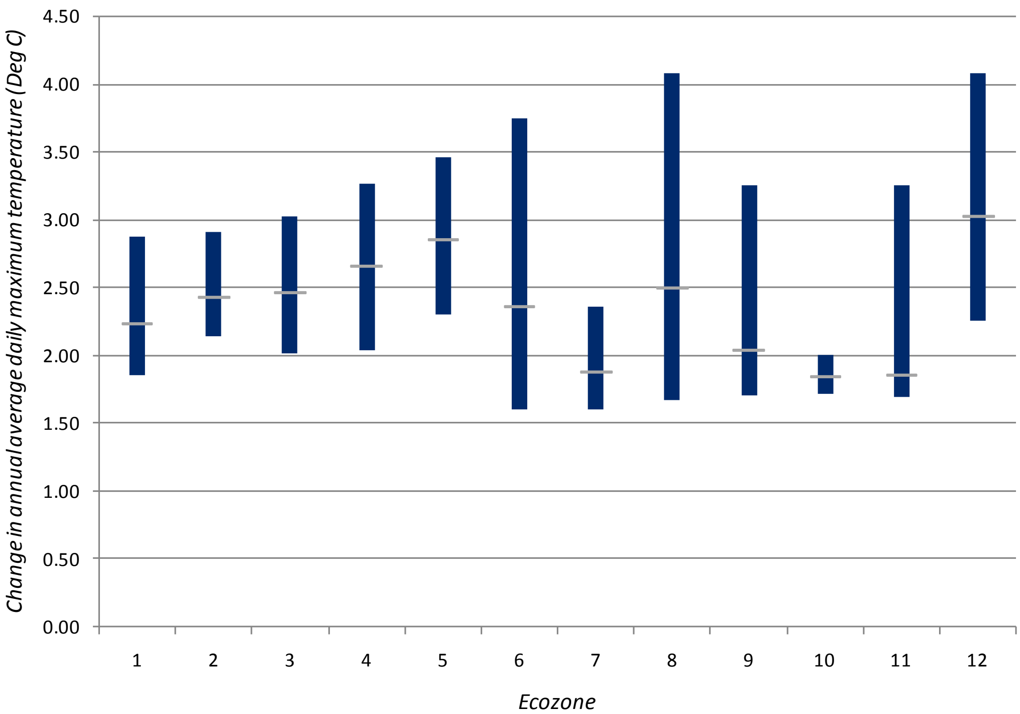
## 4.3 BASIN ANALYSIS OF CLIMATE AND HYDROLOGY PROJECTIONS FOR THE 2050 TIME SLICE

### 4.3.1 TEMPERATURE

**Projected increases in temperature show significant variability across the LMB.** Climate threat modeling undertaken for this study shows that annual average daily maximum temperatures will increase by 1.6°C to 4.1°C (Figure 4-13). **The largest changes in temperature will occur to the southeast of the basin throughout the Srepok, Sekong and Sesan river basins**, including a small area of the Srepok catchment with an increase of over 4°C. These areas are historically relatively cooler than the central part of the basin. The ecozones associated with this area—mid-elevation dry broadleaf forest and high-elevation moist broadleaf forest (Annamites)—are projected to experience the largest changes in temperature of the 12 ecozones (Figure 4-13).

From the highest increases in temperature in the southeast of the basin, the projected temperature increase gradually decreases moving north along the Annamites and south-west toward Tonle Sap and the Mekong Delta. The projected temperature increase drops sharply in the Khorat Plateau of Thailand which may experience increases as low 1°C to 2°C. To the north of the LMB, in northern Thailand and northern Lao PDR the increase in temperature is also predicted to be relatively low for the basin—below 2°C. The northern ecozones match this difference, also showing lower increases compared to the south and south-eastern ecozones (Figure 4-13).

**Figure 4-13: Projected temperature changes for LMB ecozones.** *The dark blue bars represent the range of variability within the ecozone.*

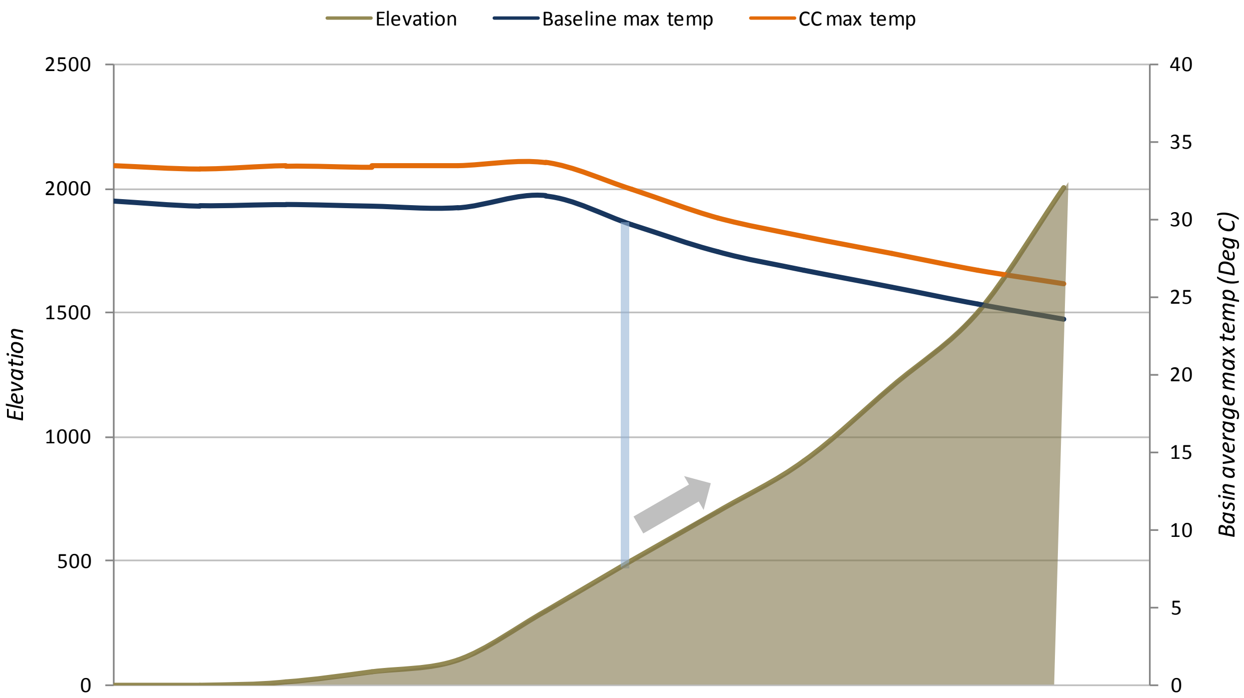



**The ecozone numbering system is described in Section 3.1.2.1*

**Increases in temperature will generally be more pronounced in the historically cooler wet season** with changes between 5% to 20% (1.7°C to 5.3°C) compared to increases of between 4.5% to 13% (1.5°C to 3.5°C) during the dry season. The seasonal differences in temperature increases are consistent throughout the basin.

**As temperatures increase across the basin there is a projected elevation shift of maximum temperatures**, particularly for elevations above 400 m (Figure 4-14). Higher temperatures that historically occur at lower elevations will shift to higher elevations. For example, areas in the basin with elevations of 500 m historically experience an average maximum temperature of around 30°C. Under climate conditions, areas at 500 masl will be more likely to experience average maximum temperatures of 32°C, while average maximum temperatures of 30°C will shift to occur at higher elevations of around 750 m. Increases in temperature will be consistent across the range of elevations in the basin.

**Figure 4-14: Temperature elevation shift in the Lower Mekong Basin due to climate change.** *Showing example shift of an average maximum temperature of 30°C from 500 m to approximately 750 m elevation*



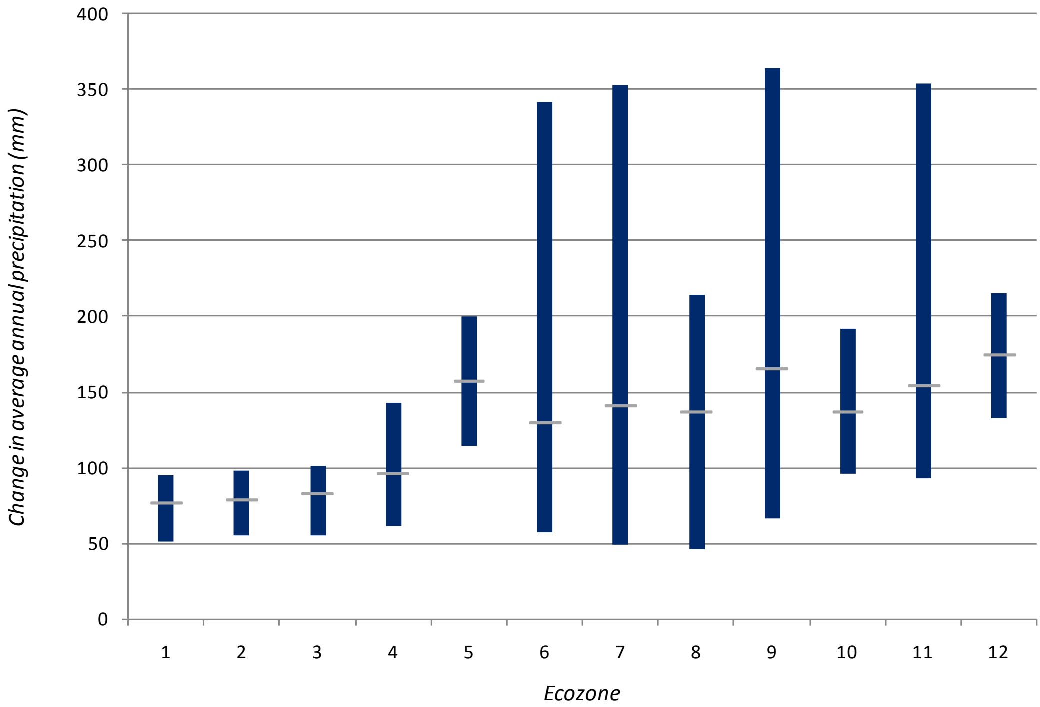

## 4.3.2 PRECIPITATION

**Annual precipitation is projected to increase by between 3% and 14% (35–365 mm) throughout the basin**. The largest increases in precipitation will occur in the historically wet areas of the central and northern Annamites and east to the floodplain between Vientiane and Pakse where increases of up to 18% or 365 mm are expected to occur. The northern mid-elevation areas of Lao PDR and Thailand may also experience a large increase in precipitation. In these historically cool and relatively dry areas increases in annual precipitation are expected to reach up to 14% or 175 mm. The ecozones associated with these areas, the low-mid elevation moist broadleaf forest and high-elevation moist broadleaf forest - North Indochina, are projected to experience the highest increases in average annual rainfall including increases of up to 350 mm (Figure 4-15).

**Lower increases in annual precipitation may occur in the Khorat Plateau, Cambodian floodplains, and the Vietnamese Delta**. In these lowland areas annual precipitation will increase by between 3% and 10%. These areas are historically drier so this translates to an increase of only 50 to 100 mm. The ecozones associated with these areas may experience significantly less changes in rainfall than the ecozones to the north and east (Figure 4-15).

The Vietnamese Central Highlands will also see a low percentage increase in precipitation of 5% to 8%. This is an area of historically low rainfall so this translates into a more significant absolute increase of up to 175 mm.

**Figure 4-15: Projected changes in annual precipitation for Lower Mekong Basin ecozones.** *Note that the dark blue bars represent the range of variability within the ecozone.*

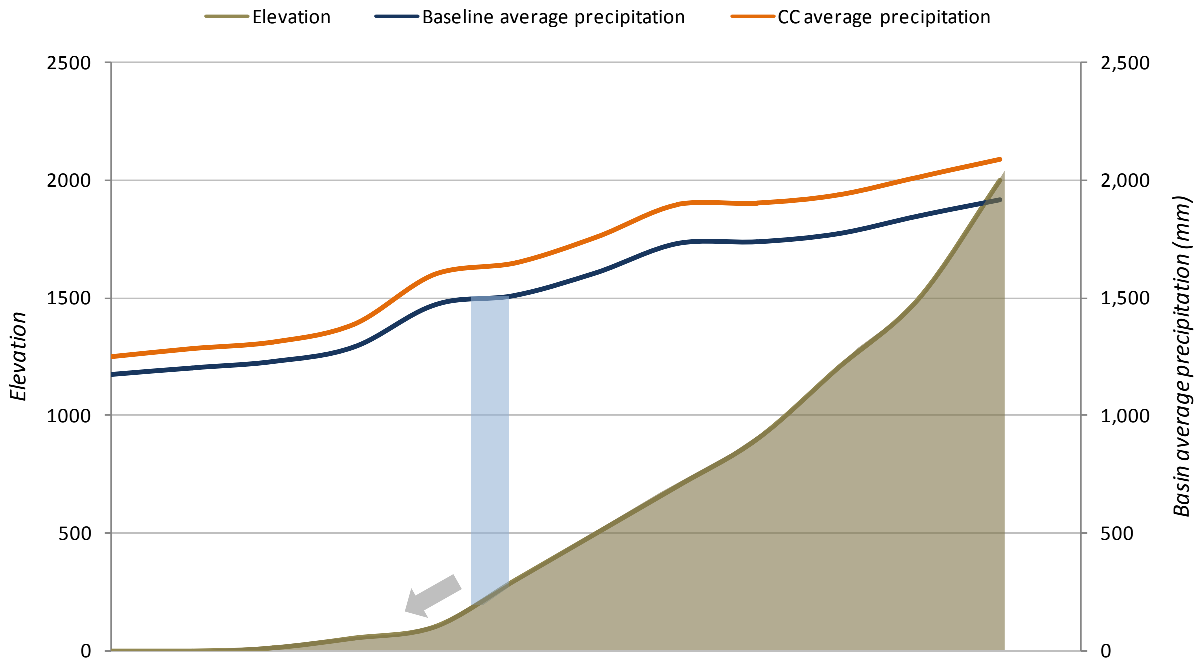



**The ecozone numbering system is described in Section 3.1.2.1*

**For the southern parts of the LMB, increases in precipitation will be coupled with increased climate variability**. Large areas of the basin south of Pakse will experience negative changes in precipitation during the dry season. During the wet season these areas will experience an increase in precipitation of 5% to 14%. This will result in seasonal differences that are significantly more pronounced in the southern areas of the basin. The northern areas of the basin may experience smaller absolute increases in precipitation in the dry season compared to the wet season therefore also increasing the variability between seasons but to a lesser degree than in the south.

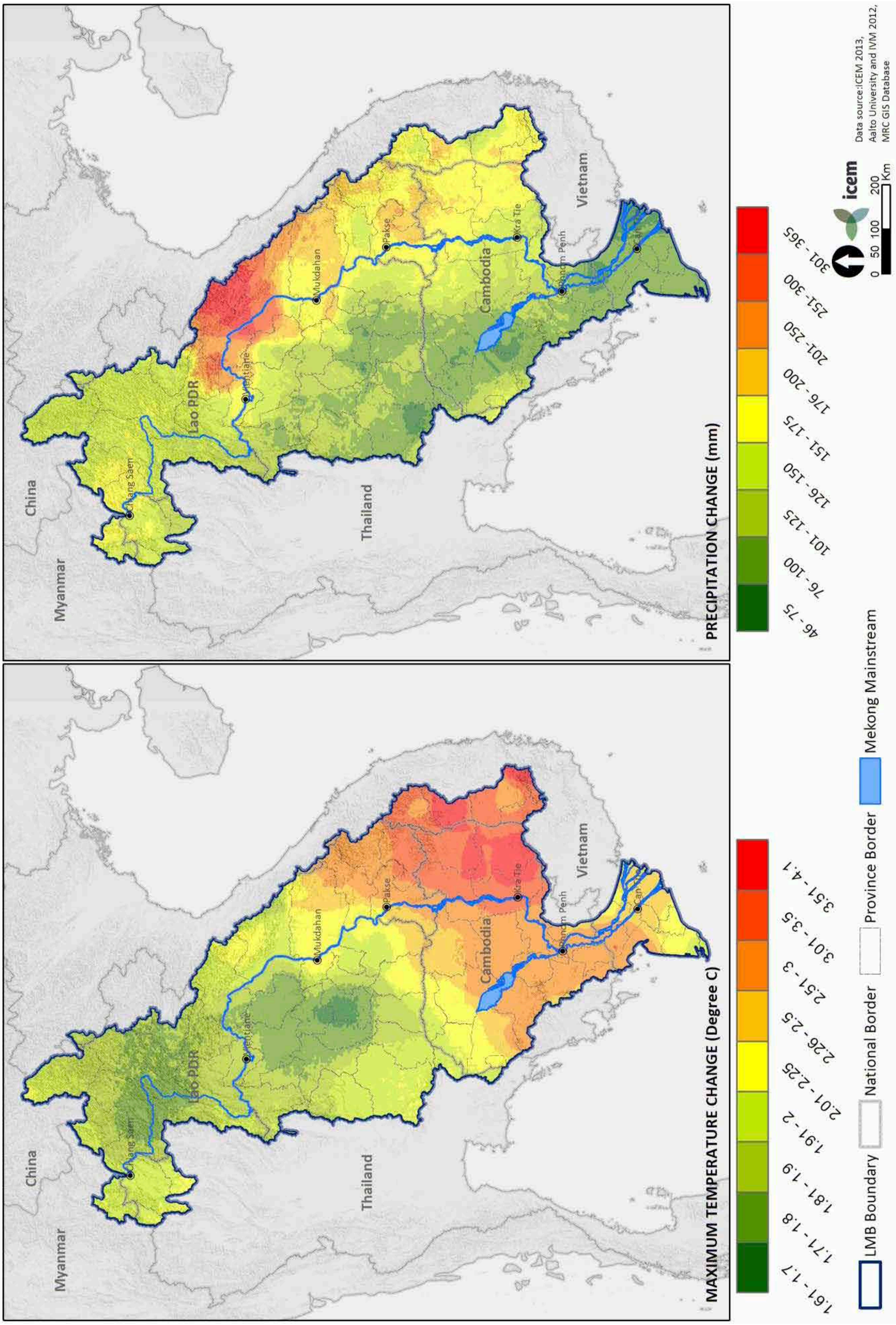
**As described above regarding temperature, changes in precipitation may lead to an elevation shift in precipitation across the basin**. Levels of precipitation that historically occur at higher elevations will now occur lower. For example average annual precipitation of 1,500 mm historically occurred at an elevation of 280 m. Under climate change conditions an average annual rainfall of 1,500 m will shift to elevations of 80 m. Increases in precipitation will be more pronounced at higher altitudes (Figure 4-17).

**Figure 4-16: Precipitation elevation shift in the Lower Mekong Basin due to climate change.** *Showing example shift of an annual precipitation of 1,500 mm from 280 m to 80 m elevation*




4 CLIMATE AND HYDROLOGY PROJECTIONS

**Figure 4-17: Projected annual average maximum daily temperature and annual precipitation changes in the Lower Mekong Basin**



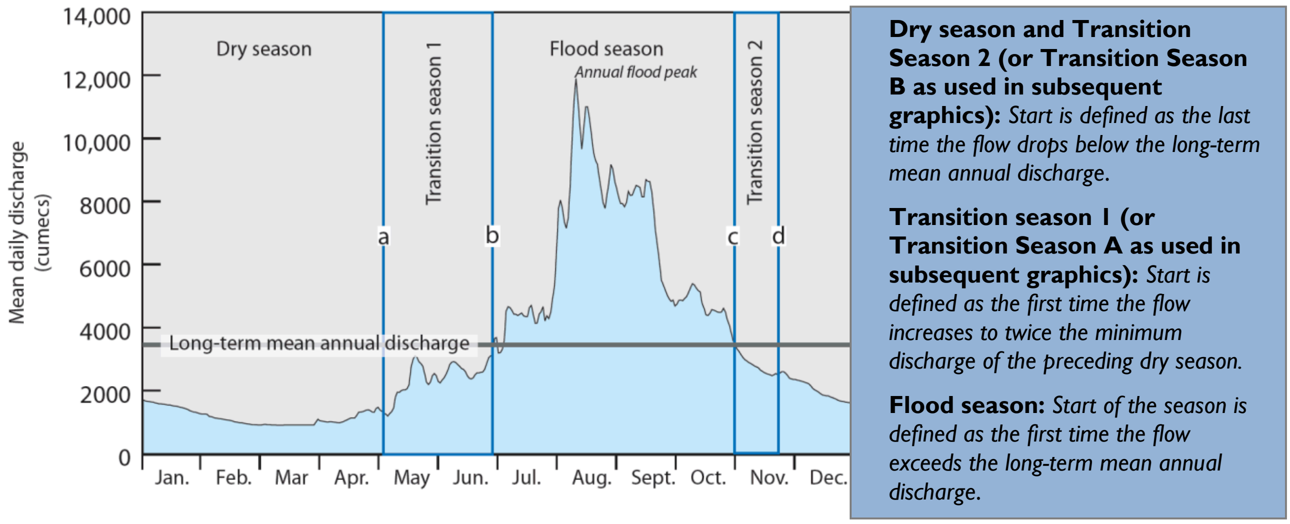
### 4.3.3 HYDROLOGY

For this study, analysis of the hydrology of the basin has focused on two components of the flood pulse: onset and duration of biological seasons and changes in flow volumes.

#### 4.3.3.1 Onset and duration of hydro biological seasons

Hydrobiological seasons take into account both the flow of the river, and the biological communities that depend on the flow. In 2009 the MRC developed definitions for four distinct seasons of the Mekong annual hydrological cycle (MRC 2009). The start and end of each season is defined by specific flow thresholds and therefore the date of the onset of seasons varies from year to year (Figure 4-18).

**Figure 4-18: Definitions for the hydrobiological seasons of the Mekong River** *(Source: MRC 2009)*




**Projections indicate significant changes in the onset of the Mekong hydrobiological seasons** due to changing patterns of rainfall and temperature (Figure 4-19 a and c). These changes include:

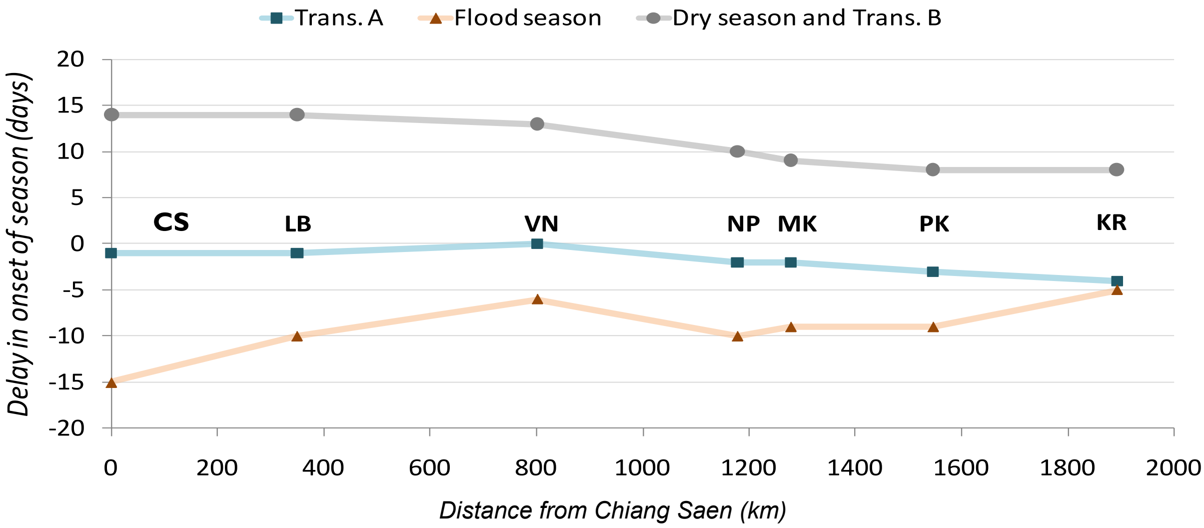
- Wet season will start 1-2 weeks earlier;
- Dry season and Transition Season B will start 1-3 weeks later;
- Transition Season A will start <1 week earlier;
- Upper sections of the river will experience the largest delay in onset of the dry season; and
- Lower reaches will experience the least delay in onset of the dry season.

Analysis of the duration of hydrobiological seasons along the Mekong River shows that **the flood season will increase and the other hydrobiological seasons will decrease in length** (Figure 4-19 b and c):

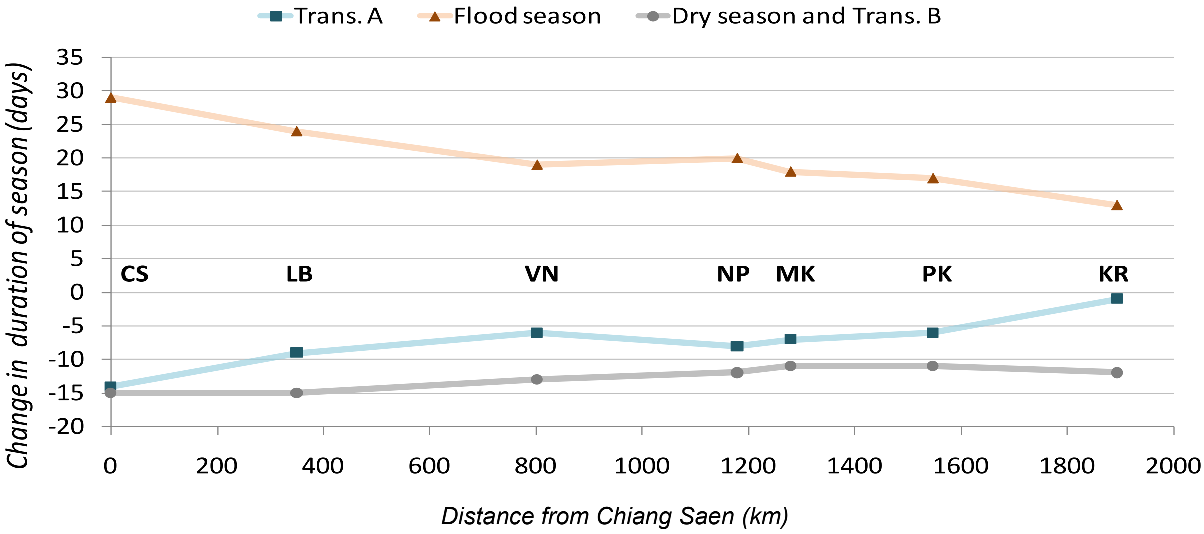
- Wet season will last 2-4 weeks longer;
- Dry season and Transition Season B will last 1-3 weeks shorter;
- Transition Season A will last 1-2 weeks shorter;
- Upper sections of the river will experience the largest increase in flood season duration; and
- Lower reaches will experience the smallest increase in flood season.

**Figure 4-19 (a-c): Climate change-induced alterations to hydrobiological seasons at seven stations along the Mekong mainstream**

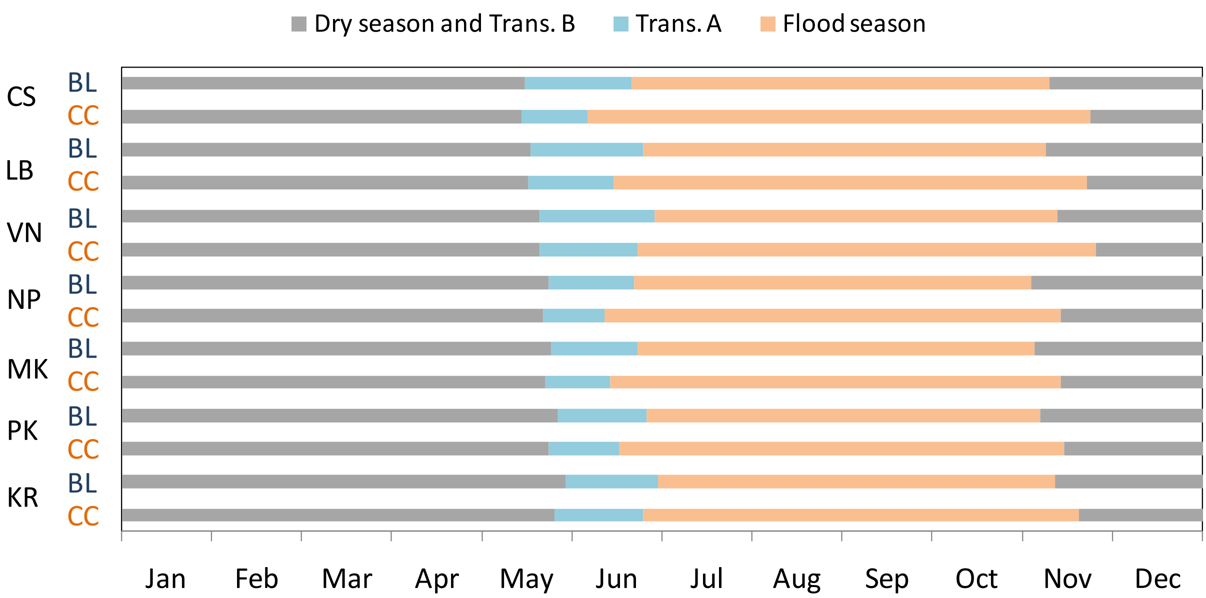
***a) Projected delay in onset of hydrobiological seasons due to climate change***




***b) Projected change in duration of hydrobiological seasons due to climate change***




***c) Timing of biological seasons under baseline and climate change conditions***



### 4.3.3.2 Changes in flow volumes

The Mekong River discharge and seasonal flow volumes increase downstream until Kratie after which the river enters a broad floodplain and flow is complicated by overland and non-channelized flow. This section concentrates changes in the flow regime between Chiang Saen in the north near the Chinese border to Kratie located just below the confluence with the Sesan, Srepok, and Sekong basins.

**Increasing precipitation throughout the basin will lead to increased annual flows in the Mekong mainstream** (Figure 4-20). Due to historically higher flows downstream the magnitude of the increased flows will be greatest in the downstream reaches while the increase relative to baseline will be greater in the upper reaches (Figure 4-21 a).

The increase in flows will not be consistent between the hydrobiological seasons. Due to the shift to longer wet seasons and shorter transition and dry seasons (Figure 4-19 b), the wet season will show a major increase in total flow volumes - reaching up to an 54,000 MCM increase at Kratie (Figure 4-21 b). Most of the stations will also experience a decrease in dry and transition season total flow volume as the seasons shorten.

The dominant feature of the Mekong flood pulse is a single flood peak during August/September. Across all stations, climate change will increase the size of the flood peak (Figure 4-21 c). The size of the increase will be smallest in Chiang Saen with a 1,200 $m^3/s$ increase, becoming more pronounced in downstream stations until reaching an increase of 6,200 $m^3/s$ at Kratie. The timing of the flood peak may only shift by a few days for most stations except for Chiang Saen where it is projected that the flood peak will be delayed by up to 14 days.

**The variability of the Mekong flood pulse will increase with climate change** (Figure 4-20). Annual minimum daily flows will increase up to 100 $m^3/s$. Annual maximum daily flows will increase by two orders of magnitude and greater reaching an increase of close to 10,000 $m^3/s$, which will mean that the variability of flows within a year will increase. The increasing variability will be greatest in the downstream reaches.

**Figure 4-20: Average annual flood pulse of the Mekong under baseline and climate change conditions**

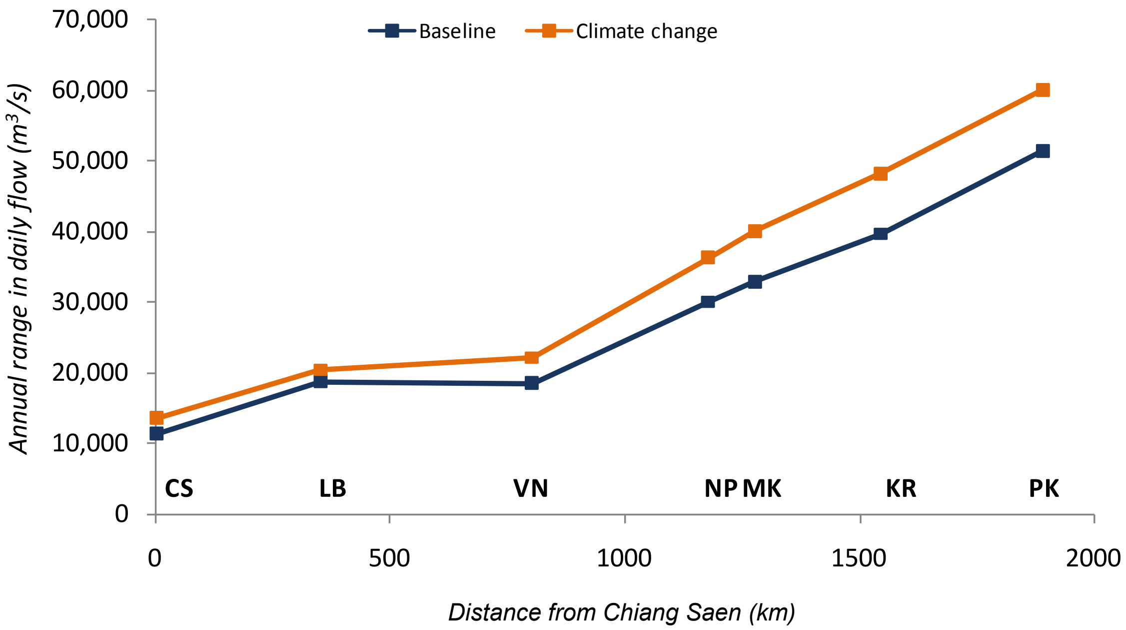
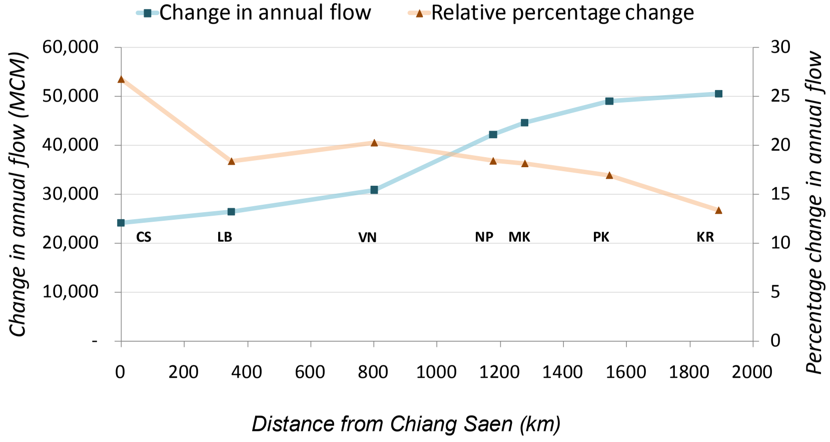
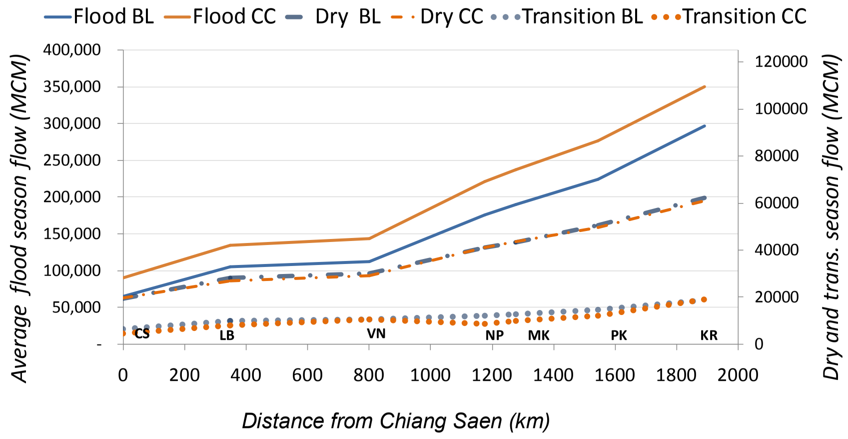


**Figure 4-21 (a-c): Projected changes in Mekong flow due to climate change for seven mainstream stations**

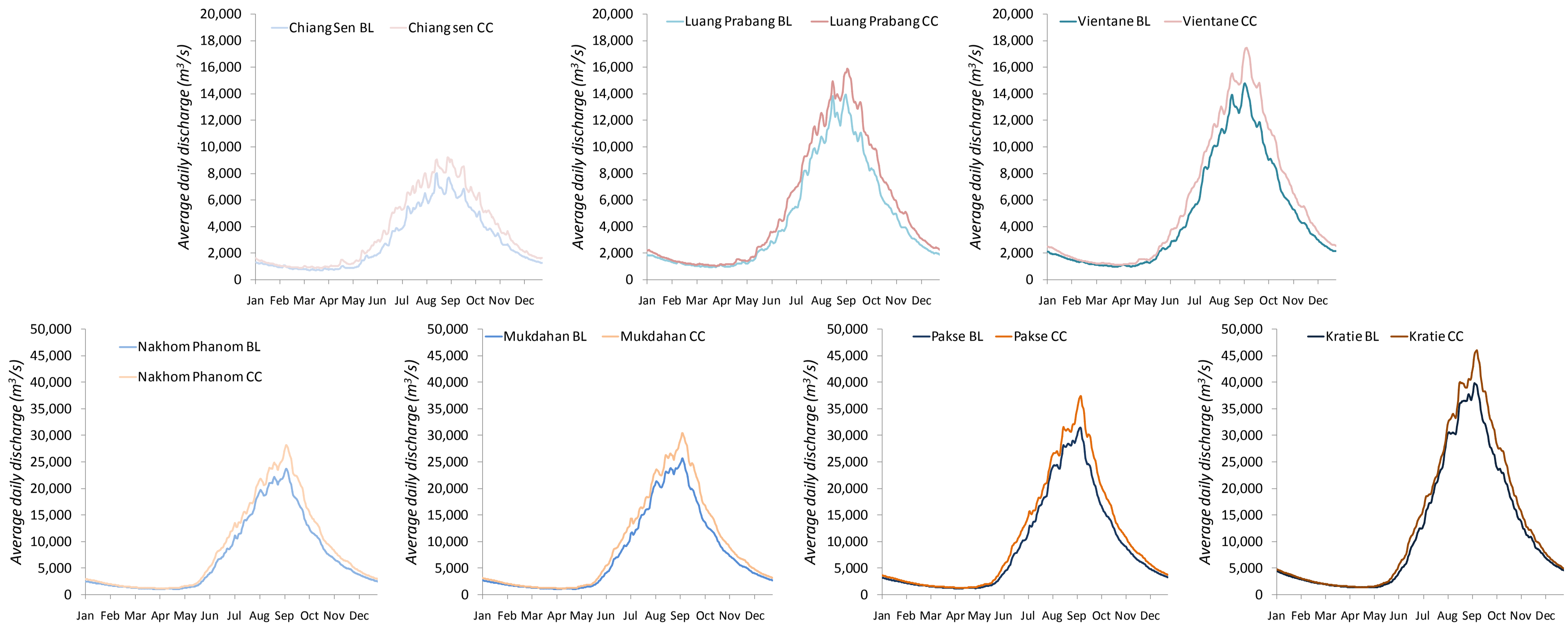
*a) Changes in annual flow volume for seven stations on the Mekong mainstream*




*b) Changes in seasonal flow volume for seven stations on the Mekong mainstream*



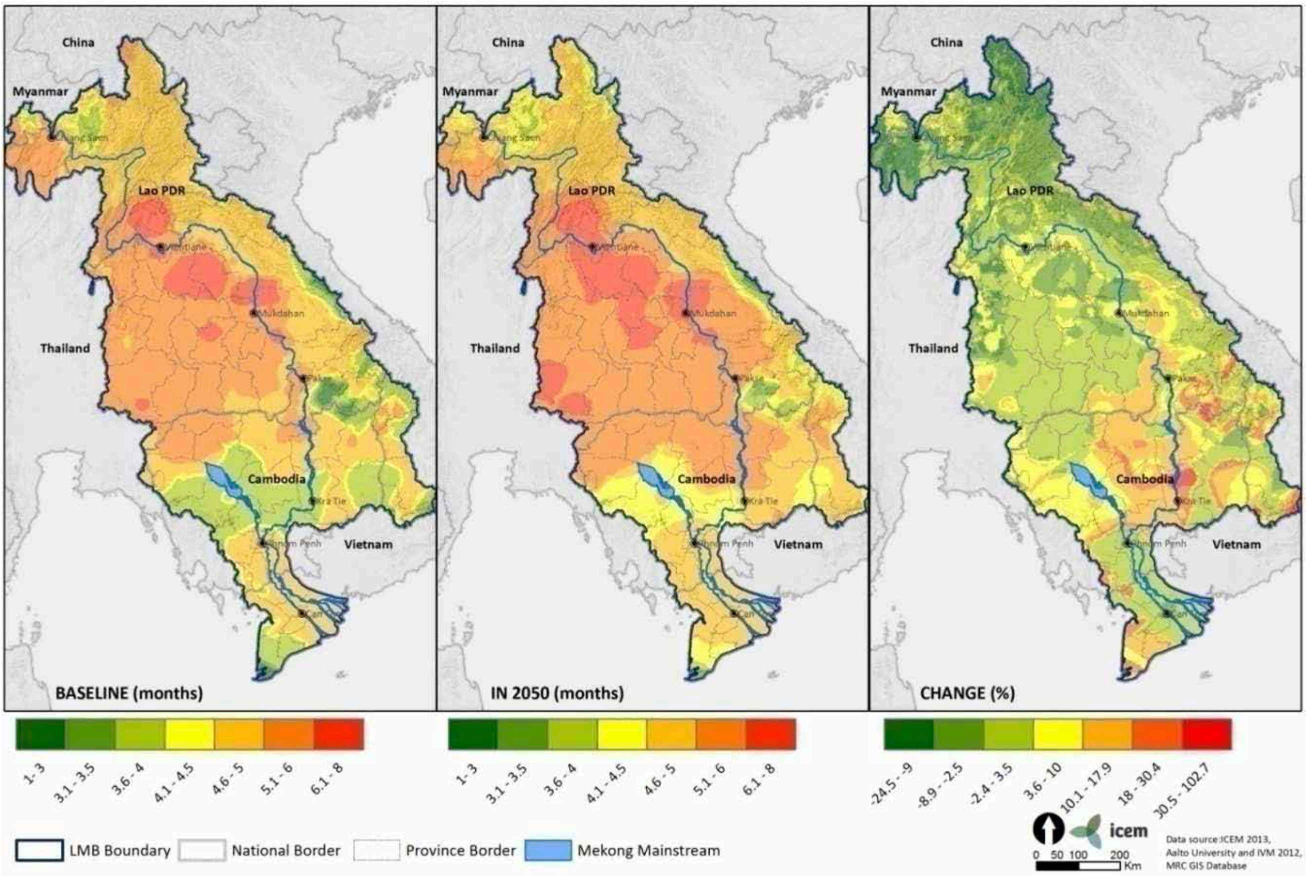

*c) Baseline and climate change hydrographs for Mekong mainstream stations*



### 4.3.4 AGRICULTURAL DROUGHT

**The period of agricultural drought per year may significantly increase in large areas in the south and east of the basin by 2050**. The study used an agricultural definition of drought taken from the FAO, where a drought month occurs when the precipitation in that month is less than 50% of the potential evapotranspiration (PET). Using this definition the Cambodian floodplain, Vietnamese Central Highlands, southern Lao PDR, and areas of the delta will experience a 10% to 100% increase in drought months—an increase of around one drought month per year. In the north of the basin in areas such as Chiang Rai and northern Lao PDR, there will be a decrease in drought months of up to 25%—a decrease of around two weeks of drought per year.

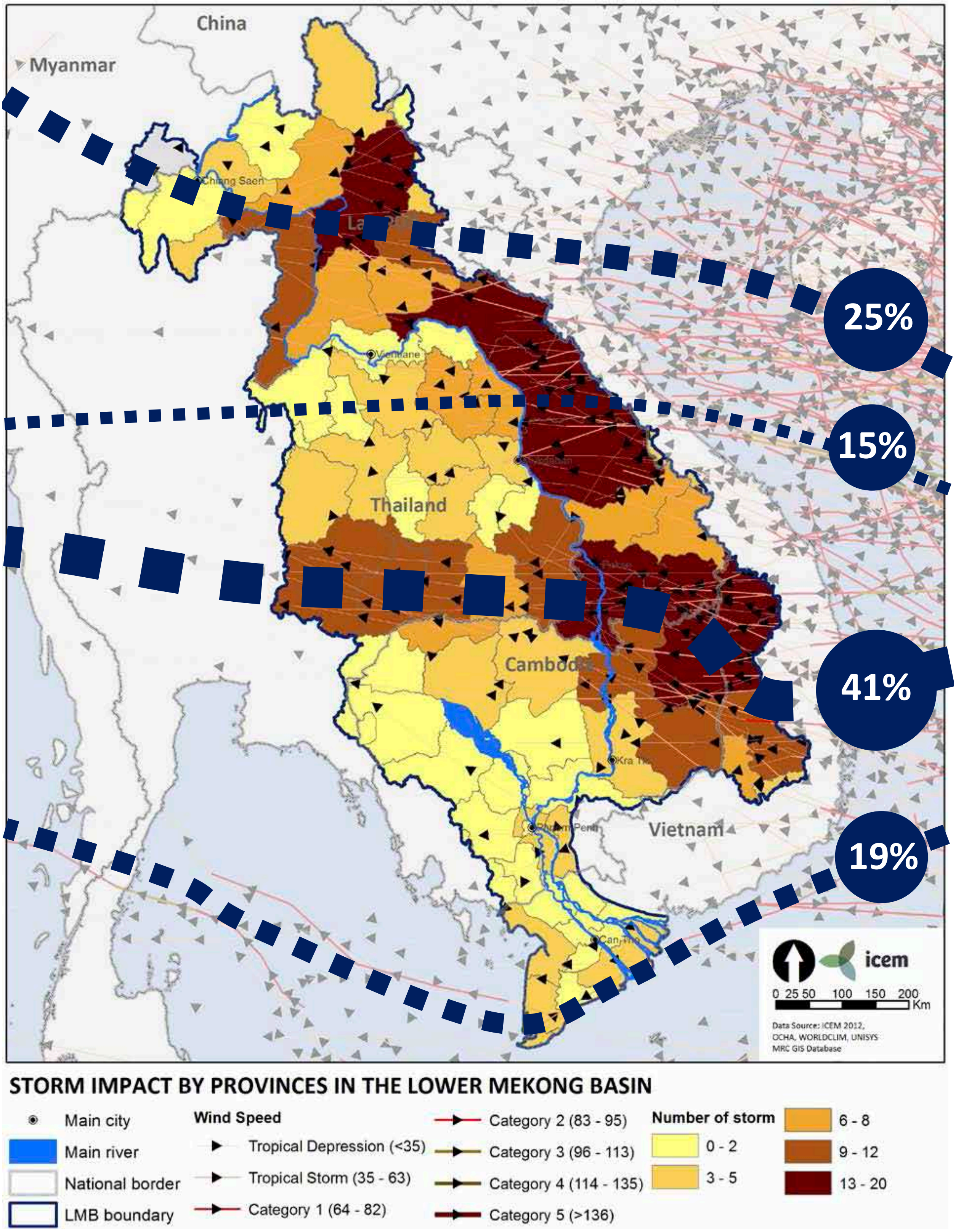
Figure 4-22: Climate change impacts on agricultural drought




### 4.3.5 CYLONES, STORMS AND PEAK PRECIPITATION

The LMB is located in the middle of two cyclone systems—the first originating over the Pacific Ocean east of the Philippines and the second originating in the South China Sea—and is therefore highly susceptible to climate-induced changes in cyclones. The basin experiences a cyclone at least once every two years and along with the potentially damaging high winds comes a sudden large amount of rainfall which may cause flooding (Figure 4-23).

**Figure 4-23: Historic frequency and intensity of tropical storm and cyclone tracks for the LMB**
*(Source data: OCHA 2012)*



Uncertainty in historical records, incomplete understanding of the physical mechanisms linking cyclones to climate, and their natural variability means it is hard to attribute changes in cyclone activity to anthropogenic influences (IPCC 2012). Partly due to this difficulty there have been no studies focused on the likely climate change impacts on the cyclone systems tracking across the Mekong region. Nonetheless, it is possible to draw some conclusions from global and regional studies on climate change and cyclones.

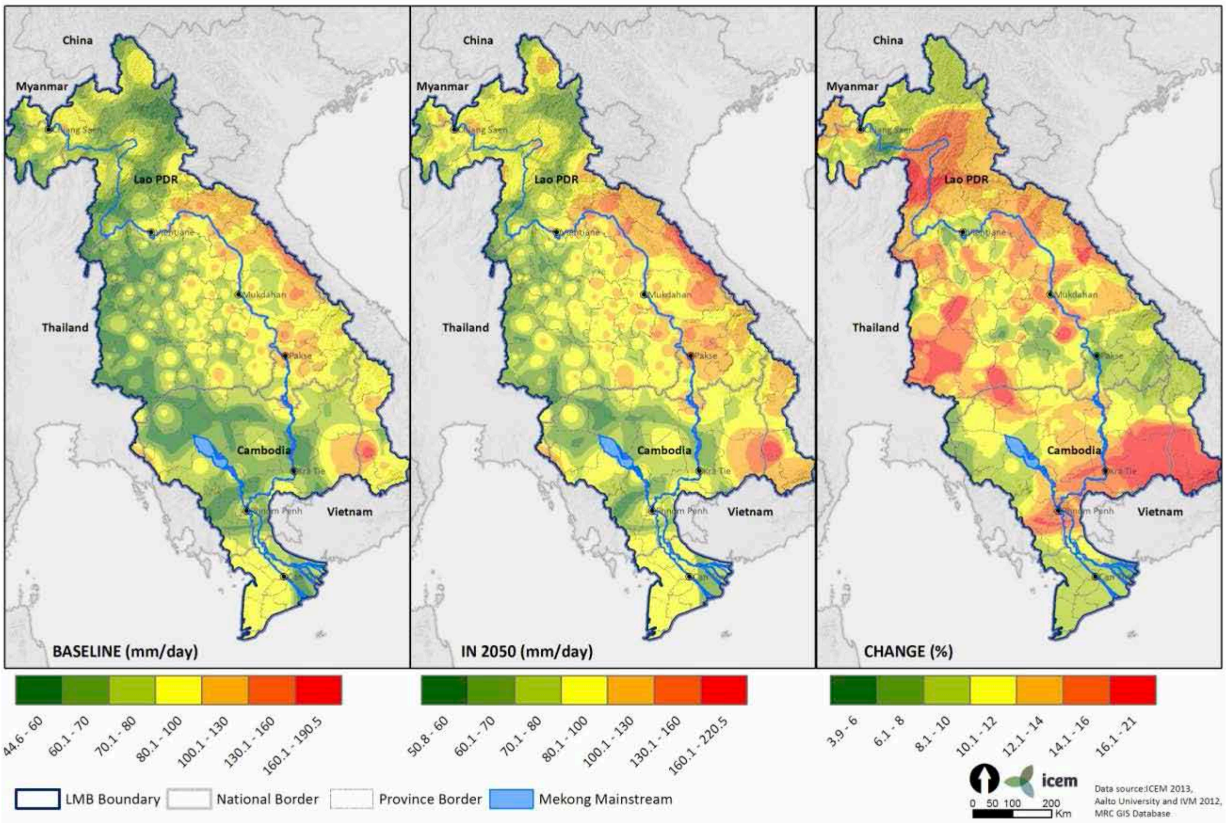
A recent IPCC report on changes in climate extremes (2012), which looked at the current state of knowledge on likely climate-induced changes in cyclones globally, concluded that with climate change it is likely that:

(i) cyclone-related rainfall rates will increase;
(ii) the frequency of cyclones will slightly decrease;
(iii) cyclone wind speeds will increase; and
(iv) the frequency of the more intense cyclones will increase substantially.

**Best global estimates suggest that average cyclone strength will increase by an order of 10%, and that the increase of the proportion of Category 4-5 cyclones will be even greater**. Based on more than 40 years of historic records and future modeling, there is consensus globally of a 5% increase in cyclone intensity for each °C increase in global surface temperatures (Holland et al. 2013). While this trend is expected to slow down in the future, the timing is uncertain such that a 2°C to 3°C increase in Mekong temperatures is likely to result in cyclone intensity increases in the order of +10%. Further a 5% increase in mean cyclone intensity would likely exacerbate extreme cyclonic conditions, inducing a ~20% increase in Category 4-5 cyclones (Holland et al. 2013).

**Projected increases in precipitation for the LMB could be compounded by increasing cyclone intensities**. Throughout the LMB there is an increase in peak daily precipitation of more than 5% (Figure 4-24). In the Srepok catchment, central Cambodian floodplain, northern Annamites and northern highlands of Thailand and Lao PDR, increases in peak precipitation exceed 16%. Increasing peak rainfall and cyclone intensity will increase the variability in Mekong rainfall affecting flash floods, hillslope erosion rates and downstream flooding.

Figure 4-24: Projected increases in peak daily precipitation for the LMB




## 4.3.6 FLOODING AND SALINE INTRUSION IN THE MEKONG DELTA

### 4.3.6.1 Flooding in the Mekong Delta

#### Average flood conditions

**Sea level rise and increasing average flood volumes will increase the depth and duration of average floods in the Vietnamese Delta and Cambodian floodplains.** Large areas of the delta which were historically rarely or never flooded to depths of 1.0 m and 0.5 m are projected to be regularly inundated to these levels. Maximum flood depths are projected to increase by over 1.0 m with the highest increases along the South China Sea coastline. Relatively minor increases in flood depth and duration are projected for the Cambodian floodplains.

The culmination of increasing average flood flows and sea level rise will significantly alter the flooding regime of the Vietnamese Delta and also have impacts on the Cambodian floodplains (Figure 4-25). In the Vietnamese Delta:

- Approximately 19% of the total delta area (600,000 ha) that historically was rarely or never flooded to a depth of 1.0 m will experience floods at this level or greater for four or more days during an average flood year.
- The area of the delta that is rarely or never flooded to a depth of 0.5 m or greater during an average flood year will change significantly—from nearly 60% to 10% of the total delta area (1.9 million ha to 300,000 ha).
- There will be a sharp increase in the area of the delta that is inundated to 0.5 m for over 121 days from 75,000 ha to close to one million ha.

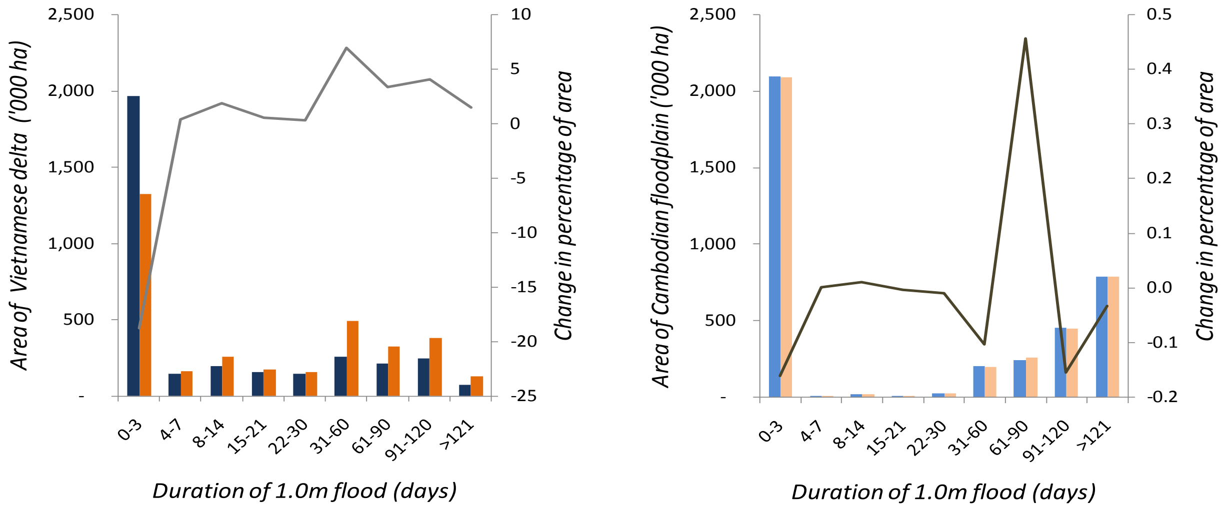
- During an average flood year the area of delta flooded to over 1.0 m depth will increase from 45% to 57% under projected climate conditions—an increase of over 650,000 ha.

In the Cambodian floodplains during an average flood year:

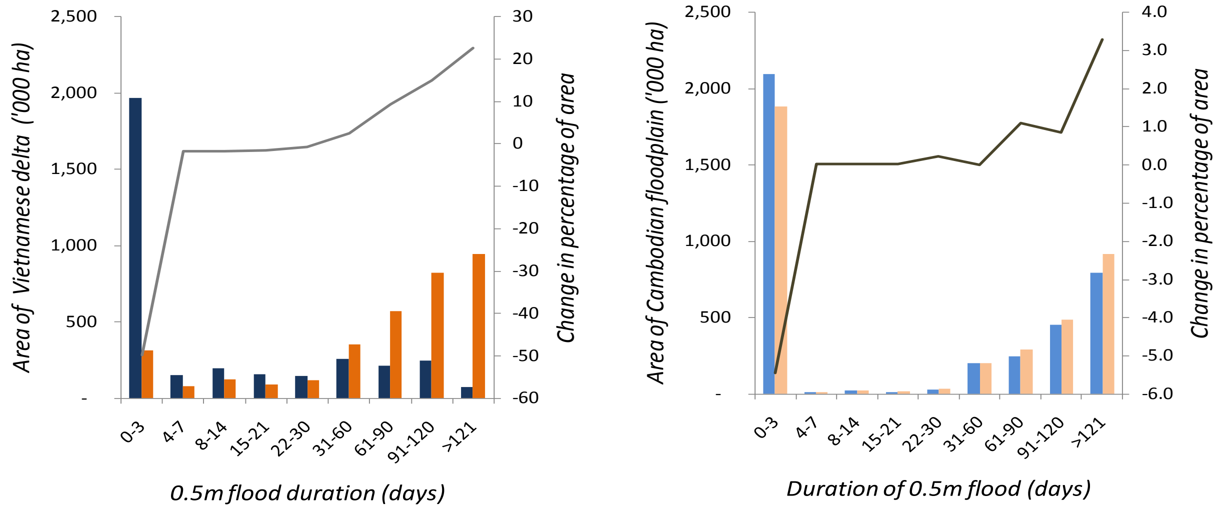
- There will be relatively minor changes in flood depths and durations compared to the Vietnamese delta
- Less than 1% of the total floodplain area (6,000 ha) of historically rarely flooded land in the floodplain will experience floods of over 1.0 m for four or more days a year.
- Approximately 210,000 ha (5% of the total floodplain area) of historically rarely flooded land in the floodplain will experience floods of over 0.5 m for four or more days a year.
- The area with a maximum flood depth of two to eight meters will increase by over 5,000 ha (less than 1%) of the total floodplain area.

**Figure 4-25 (a-c): Cambodian floodplain and Vietnamese Delta flood duration and depth for average flood conditions & SLR**

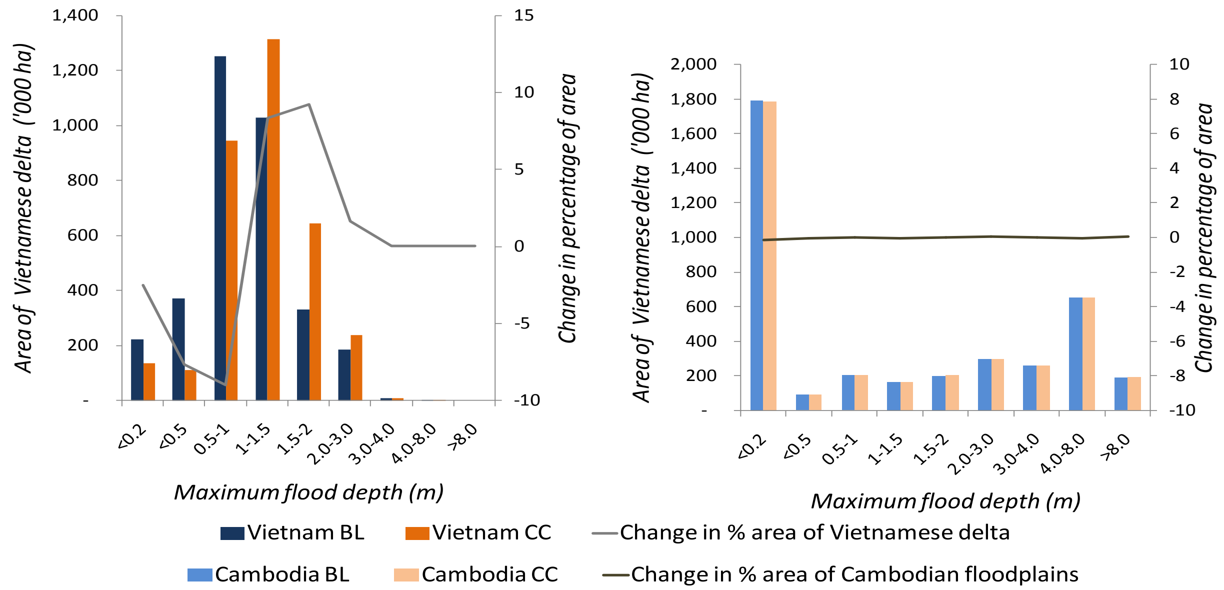
*a) Duration of 1.0 m flood depth*




*b) Duration of 0.5 m flood depth*




*c) Maximum flood depth*



### Extreme flood events

**Sea level rise, increasing extreme flood[21] volumes and escalating cyclone activity will increase the depth and duration of extreme floods in the Vietnamese Delta. In Cambodia extreme floods will increase in depth and generally increase in duration**—one exception is that less area will be inundated by floods of 1.0 m depth for over four months. This indicates that the volume of extreme floods will increase but the duration will decrease for the very long events.

The implications of increasing extreme flood flows and sea level rise will alter the regime of extreme floods in the Vietnamese Delta (Figure 4-26):

- There will be an increase in the area of the delta that is inundated to 1.0 m for over 15 days from 1,320,000 ha to 2,070,000 ha (from 39% to 61% of the delta area). In particular, 660,000 ha (approximately 20% of the total delta area) that historically was rarely or never flooded to a depth of 1.0 m will experience floods at this level or greater for four or more days during an extreme flood year.
- During an extreme flood year the area that is inundated to 0.5 m depth for over 121 days will more than double from 507,000 ha to 1,051,000 ha.
- Approximately 14% of the total delta area (462,000 ha) that historically was rarely or never flooded to a depth of 0.5 m will experience floods at this level or greater for four or more days during an extreme flood year.
- There will be a sharp increase in the area with maximum flood depth of over 1.0 m from 1,805,000 ha to 2,442,000 ha (from 10% to 22% of the delta area). The largest increase in area will be for maximum flood depth of 1.5-2.0 m, which will increase in area from 354,000 ha to 754,000 ha.

In the Cambodian floodplains during extreme floods (Figure 4-26):

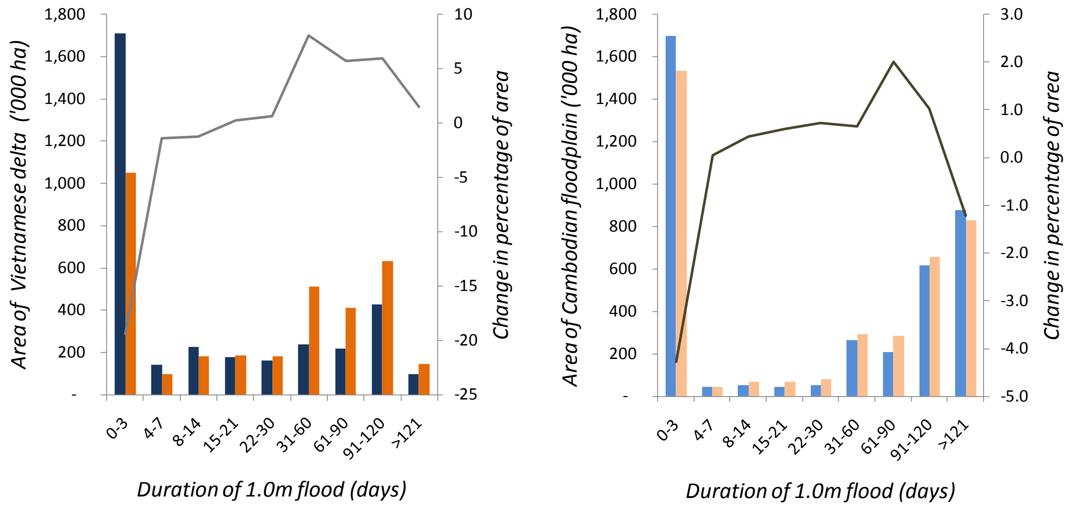
- There will be relatively minor changes in flood depths and durations during extreme floods compared to the Vietnamese Delta.
- A total of 165,000 ha (4 % of the total floodplain area) of historically rarely flooded land in the floodplain will experience floods of over 1.0 m for four or more days a year.
- A total of 124,000 ha (3% of the total floodplain area) of historically rarely flooded land in the floodplain will experience floods of over 0.5 m for four or more days a year.
- The area with maximum flood depth of over 2.0 m will increase from 1,810,000 ha to 2,030,000 ha (from 47% to 53% of the floodplain area).
- The floodplain area inundated to 0.5 m or 1.0 m depth or over 121 days will decrease by around 50,000 ha. This indicates that extreme flood volumes will increase but the duration may decrease.



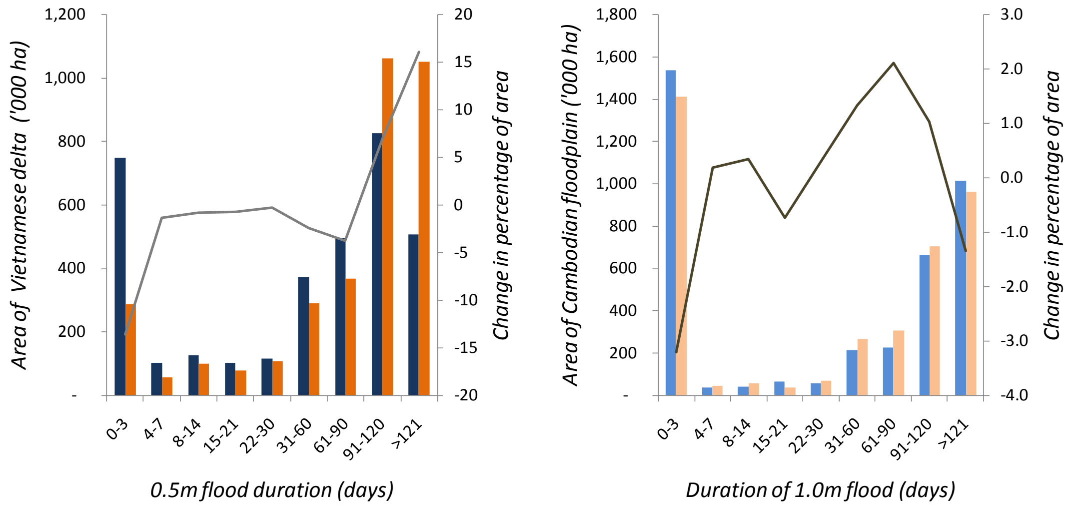
[21] The 1 in 100 yr flood (P1%)

**Figure 4-26 (a-c): Cambodian floodplain and Vietnamese Delta flood duration and depth for extreme flood events and SLR**

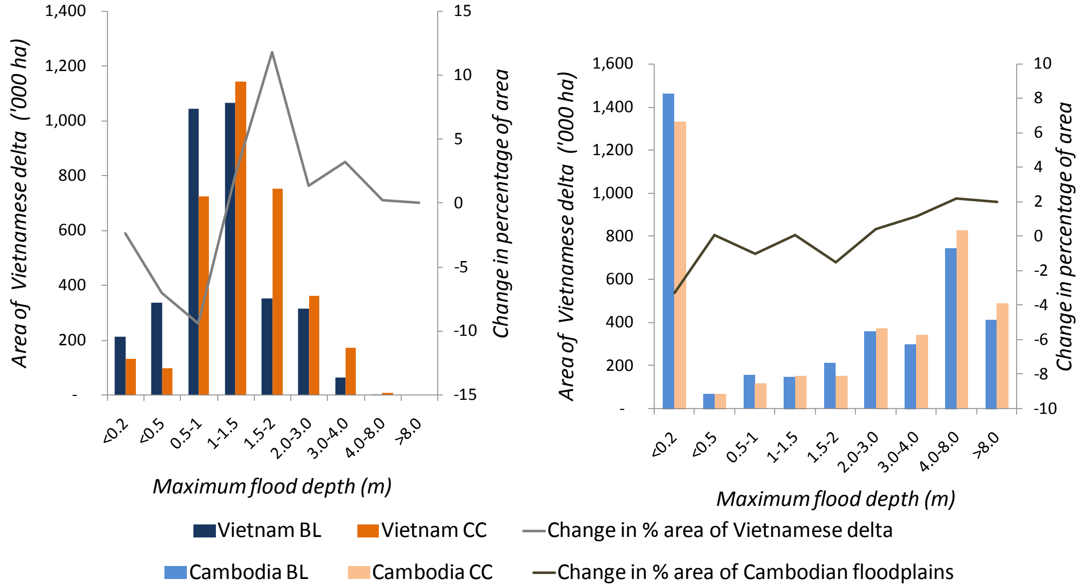
*a) Duration of 1.0 m flood depth*




*b) Duration of 0.5 m flood depth*

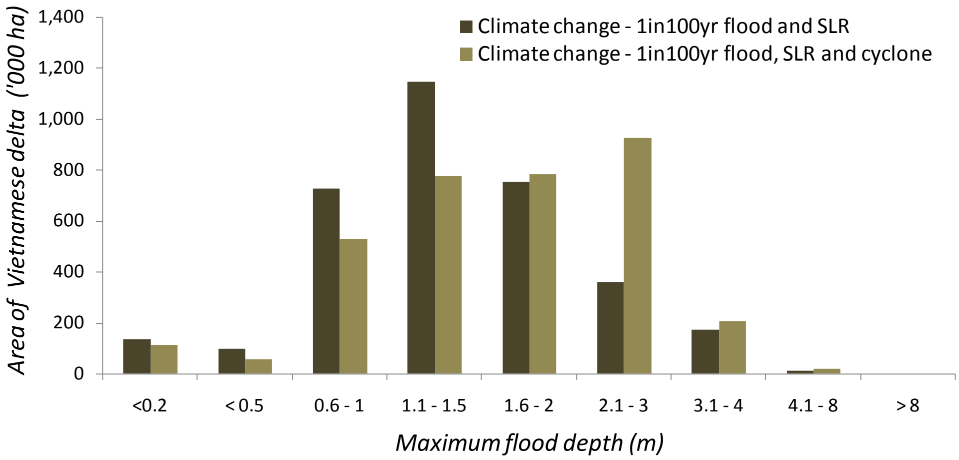



*c) Maximum flood depth*



**When cyclones coincide with extreme floods and high tides, the maximum flood depth will increase drastically in the Mekong Delta (Figure 4-27).** The addition of cyclone impacts on top of extreme flood and sea level rise will lead to increases in the area flooded to a depth of over 1.5 m from 1,300,000 ha to 1,928,000 ha (from 58% to 72% of the delta area). Cyclones will not significantly impact on Cambodian flooding.

**Figure 4-27: Comparison of maximum flood depth for climate change scenarios with and without cyclone impacts**




### 4.3.6.2 Salinity in the Mekong Delta

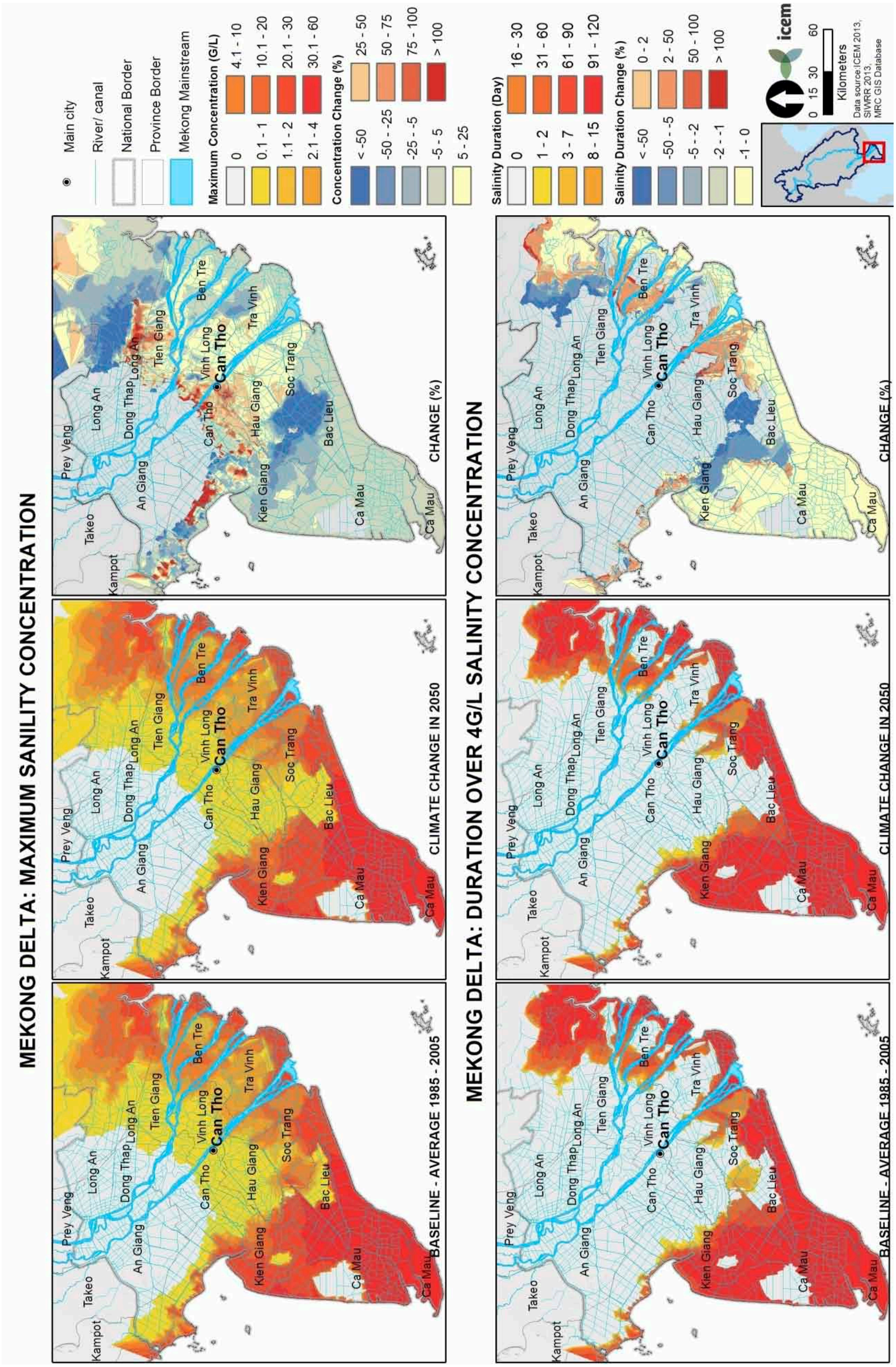
Modeling of changes in salinity due to increasing average floods and 0.3 m sea level rise has shown that **large areas of the delta will experience minor changes in maximum salinity and annual duration at a salinity of 4 g/L** (Figure 4-28). A total of 1,200,000 ha of the delta will experience minor changes in maximum salinity of between -5% to 5%. Similarly, 2,000,000 ha will experience a -2% to 2% change in number of days per year with a salinity concentration of more than 4 g/L.

**The greatest changes in salinity will occur at the dry season wetting front,** which represents the extent of coastal influences into the delta (Figure 4-28). In the central delta provinces of Can Tho, Dong Thap, Hau Giang, Kien Giang, Tien Giang, and Vinh Long, over 133,000 ha will experience an increase in maximum salinity concentration of over 50%. The 4 g/L salinity contour intrusion will creep landward and there will be areas subjected to salinity levels that they historically never or rarely experienced.

**Climate change-induced changes in the extent and duration of saline intrusion in the Mekong Delta are highly sensitive to the use of human built water control infrastructure**. As one of the most productive areas in the basin, the delta contains more than 3,900 canal structures and more than 5,000 sluice gates and hydraulic headworks. Reductions in salinity concentration and duration in the delta (for example Hau Giang Province will experience a decrease in concentration of nearly 50%), is primarily due to the increase in Mekong river flows during the dry season combined with the high connectivity of the delta which distributes river flow throughout the delta and reduces the hydraulic gradient driving saline intrusion. Other studies reflect similar results (see for example GIZ 2012).

In addition, the impact of saline intrusion on some provinces like Kien Giang is likely to be underestimated because the study team has utilized a 2005 map of canal and sluice gate infrastructure, at which time significant areas of north-western Kien Giang were protected from saline intrusion in the interests of rice cultivation. Today the sluice gates in these areas are now open as farmers switch to shrimp aquaculture.

**Figure 4-28: Vietnamese Delta maximum salinity concentration and duration at 4 g/L for average flood conditions and SLR**



## 4.4 HOTSPOT RANKING

### 4.4.1 HOTSPOT RANKING

The study team used the climate threat modeling results to identify the most threatened ecozones, catchments, provinces, and protected areas. Table 16 summarizes the ten most threatened areas for each of these spatial units and the reason they were identified as highly threatened.

**Table 16: Most threatened ecozones, catchments, provinces and protected areas in the LMB.** *Note that the main threat is given for each of the areas in bold using the following notation*[22]

| Ecozones | Catchments | Provinces | Protected areas |
|---|---|---|---|
| High elevation moist broadleaf forest – Annamites **TW** | Hoaag Hua **PD** | Phayao **PD** | Bi Dup-Nui Ba Nature Reserve **TW** |
| Lower floodplain(Pakse to Kratie) **TW** | Nam Hinboun **PD** | Nakhon Phanom **PD** | Kun Jae **PD** |
| Mid floodplain (VTE to Pakse) **PW** | Nam Thon **PD** | Chiang Mai **PD** | Kon Ka Kinh Nat.Park **TW** |
| High-elevation moist broadleaf forest - North Indochina **PD** | Nam Mae Ing **PD** | Gia Lai **TW** | Doi Phu Nang Nat. Park **PD** |
| Low-elevation dry broadleaf forest **PW** | Nam Kam **PD** | Mukdahan **PD** | Huiy Huad **PD** |
| Mid-elevation dry broadleaf forest **PW** | Huai Ho **PD** | Lam Dong **TW** | Khammouan Limestone Nat. Biodiversity Area **PD** |
| Tonle Sap swamp forest and lower floodplain **TW** | Huai Thuai **PD** | Khammouan **PD** | Chiang Dao National Park **PD** |
| Low-mid elevation moist broadleaf forest **PW** | Huai Bang Haak **PD** | Kon Tum **PD** | Pu San **PD** |
| Upper floodplain (CS to VTE) **PW** | Huai Bang Sai **PD** | Chiang Rai **TW** | Mae Phang National Park **PD** |
| Delta mangroves and coastal wetlands **PW** | Nam Mang Ngai **PD** | Ratanak Kiri **TW** | Nam Theun Ext. Nat. Biodiversity Area **PD** |

**There are three main areas within which most of the hotspots are located: northern Thailand, the northern Annamites and the 3S basins**. In the north of Thailand and in the northern Annamites area of central Lao PDR major percentage increases in dry season precipitation will threaten these higher elevation areas. Year-round increases of maximum temperature,

[22] PD - percentage change in dry season precipitation is the main climate change threat for the area
PW - percentage change in wet season precipitation is the main climate change threat for the area
TW - percentage change in wet season temperature is the main climate change threat for the area
TD - percentage change in dry season temperature is the main climate change threat for the area

particularly during the wet season, will mean that areas to the east and northeast of Cambodia and the Vietnamese Central Highlands are highly threatened.

Many of the hotspots have been identified as highly threatened by increases in dry season precipitation. Although increases in precipitation during the dry season may be relatively small in absolute terms they may have significant positive or negative impacts on ecosystems that are accustomed to the historical rainfall pattern. For example much of the increase in dry season precipitation is projected to occur later in the season during April and May. These months are common planting months in the basin for crops such as rainfed rice, maize and soya. Rainfall events during critical stages in the planting season of these crops can negatively affect crop production, leading to reduced yields or harvest losses.

Note that some areas to the south of the basin will experience drier dry seasons—i.e., negative changes in precipitation. The absolute value of the percentage change was used to assess the threat for these areas but they were not identified as highly threatened because the percentage change is relatively small.



#### 4.4.1.1 Ecozones

The two most highly-ranked hotspot ecozones, High elevation moist broadleaf forest—Annamites and Lower floodplain, wetland, lake (Pakse to Kratie), will be highly threatened by increases in temperature during the wet season of up to 13%. These two ecozones are primarily located in the southeast of the basin where temperature increases are projected to be greatest.

The third and fourth-ranked ecozones are highly threatened due to changes in precipitation. The Mid floodplain wetlands (Vientiane to Pakse) ecozone will see large increases in both wet and dry season precipitation. The high-elevation moist broadleaf forest—North Indochina ecozone will experience an increase in dry season precipitation of over 10%.

#### 4.4.1.2 Catchments

The top ten ranked hotspot catchments are highly threatened by changes in precipitation during the dry season. The catchments are located in the northern Annamites and to the north of Thailand where changes in dry season precipitation may reach up to 18%. Decreasing dry season precipitation may lead to decreasing dry season flow in these catchments.

#### 4.4.1.3 Provinces

All four countries of the LMB are represented in the top 10 most threatened provinces. There are five Thai provinces that are located in the areas to the north and to the east on the Lao PDR border and may experience major percentage changes in dry season precipitation of 14% to 17%. The three Vietnamese provinces are located in the Central Highlands and are projected to experience large increases in maximum temperature of around 15% during the wet season. The one Lao PDR province, Khammouan, is located in the northern Annamite area and may experience large year-round increases in precipitation. The only Cambodian province in the top ten is Ratanakiri. This province is located to the east of the basin next to the Vietnamese Central Highlands and is projected to experience high year- round increases in temperature including up to 14% increase in the wet season.

#### 4.4.1.4 Protected area clusters

The Bi Dup—Nui Ba Nature Reserve located in the Vietnamese Central Highlands—has been identified as the protected area most threatened by climate change. This reserve is projected to experience changes in maximum temperature during the wet season of over 17%. Kon Ka Kinh National Park also located in the Vietnamese Central Highlands is the only other protected area in the top ten that is most threatened by temperature changes. This priority zone for the protection of biodiversity in Vietnam may experience a close to 17% increase in wet season temperatures.

The remaining eight highly threatened protected areas are located in the northern Thai and central Lao PDR areas which may be threatened by major increases in dry season precipitation.

### 4.4.2 PRIORITY PROVINCES

The study team applied additional considerations including flooding and representativeness to identify the final list of priority provinces (Figure 4-29):

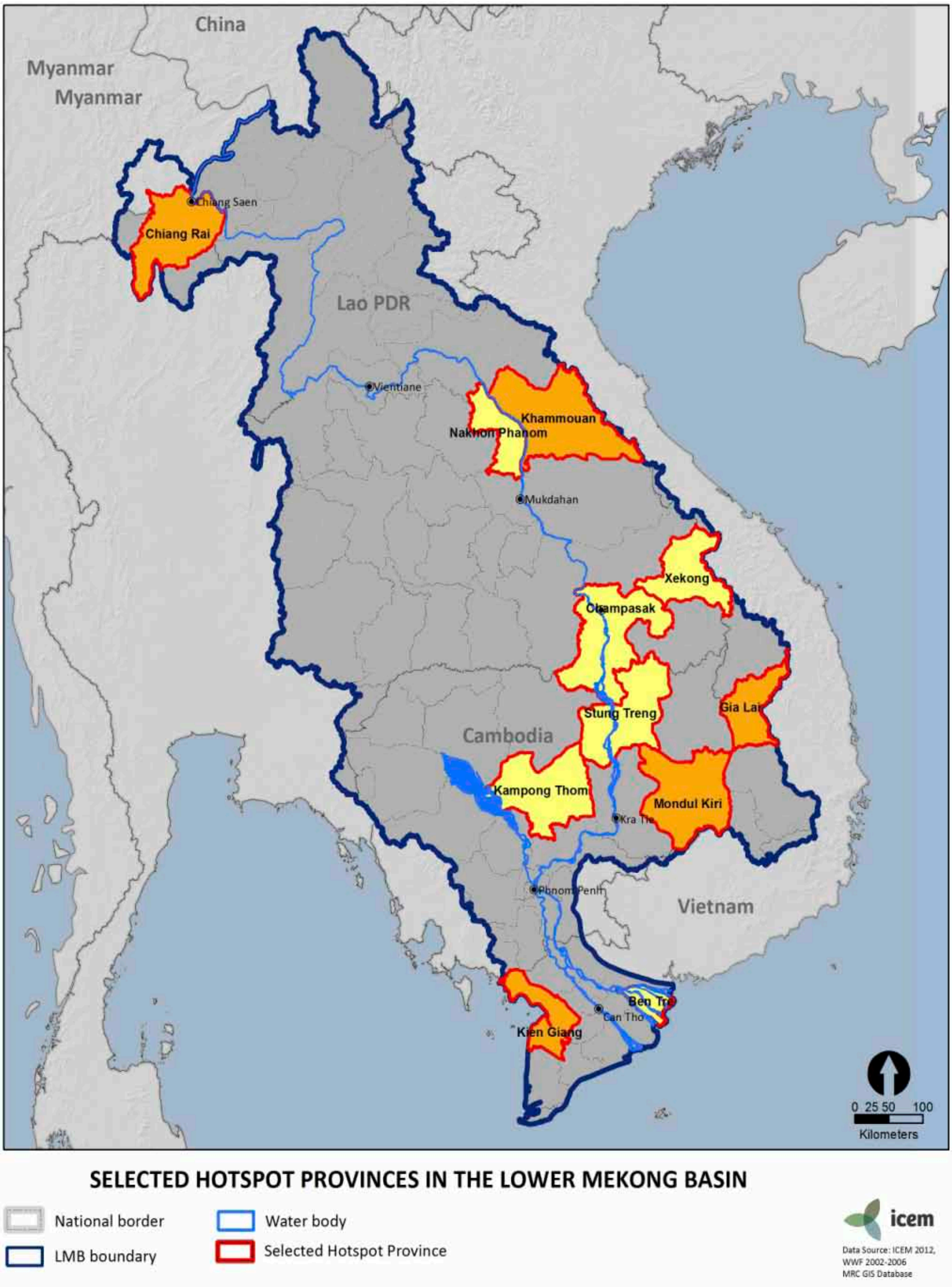
- **Primary priorities** (all theme groups undertook vulnerability and adaptation assessments for these provinces): Kien Giang, Mondulkiri, Gia Lai, Chiang Rai, and Khammouan.
- **Secondary priorities** (theme groups only undertook vulnerability and adaptation assessments in the provinces relevant to their theme): Nakhon Phanom, Kampong Thom, Sakon Nakhon, Stung Treng, Champasak, Ben Tre, and Sekong.

The provinces in eastern Cambodia and the Vietnamese Central Highlands are highly threatened due to large increases in wet season temperature.

The provinces in central Lao PDR and northern Thailand and Lao PDR are highly threatened due to major percentage increases in dry season precipitation.

Kien Giang is highly threatened by increases in flood height and duration projected to occur because of increasing flood levels of the Mekong and sea level rise.

**Figure 4-29: Selected priority provinces in the LMB.** *Primary priorities shaded in orange and secondary priorities shaded in yellow.*



## 4.5 ANALYSIS OF CLIMATE AND HYDROLOGY PROJECTIONS FOR PRIORITY PROVINCES

There is considerable variability in the changes in climate projected for the priority provinces. **The Cambodia and the Vietnamese provinces are projected to experience large increases in temperature. The Lao PDR and Thai provinces are projected to undergo major increases in precipitation and Kien Giang is highly threatened by inundation caused by sea level rise** (Table 17 and Table 18). To assist the theme groups in undertaking vulnerability assessments and adaptation planning the study developed climate change threat profiles for each of the priority provinces. These profiles provide detailed analysis of climate threats including temperature, precipitation, flows, droughts, storms, and soil water availability. The priority province climate change profiles are provided in Annex 1.

The following section highlights the key changes in climate for each of the primary priority provinces.

### 4.5.1 CHIANG RAI

**Chiang Rai Province in Thailand is projected to experience some of the largest relative increases in precipitation within the LMB with annual precipitation increasing by 9% to 18%** (Figure 4-30). The greatest percentage increase in precipitation is projected to occur in December with a close to 50% increase in precipitation from 11 to 16 mm/month. In the wet season the largest increase will be up to 30 mm in September (11% increase).

**Temperature increases are moderate across the province** (between 5% to 8%). Chiang Rai Province has a large variation in elevation between the lowlands running north to south through the center of the province and the higher elevations to the east and west. This elevation range causes a minor variation in temperature within the province.

**Figure 4-30: Chiang Rai projected change in annual average precipitation**

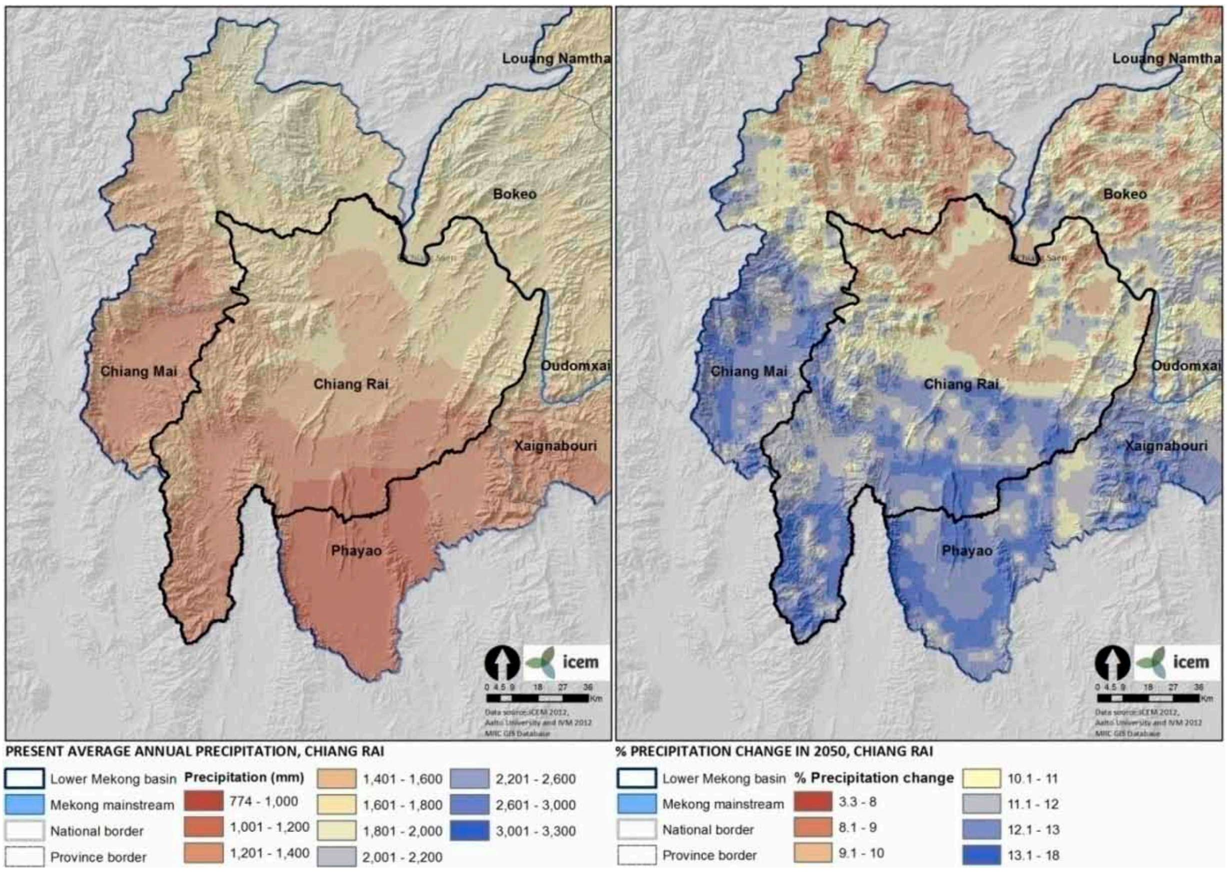


**Table 17: Climate projections for primary priority provinces**

| | Chiang Rai | Gia Lai | Kien Giang | Khammouan | Mondulkiri uplands |
|---|---|---|---|---|---|
| **Daily maximum temperatures** | **Increase** of between 1°C to 2°C throughout the year | **Increase** of between 1°C to 5°C throughout the year | **Increase** of between 2°C to 3°C throughout the year | **Increase** of between 2°C to 4°C throughout the year | **Increase** of between 2.5°C to 5°C throughout the year |
| **Daily minimum temperatures** | **Increase** of between 0°C to 2°C throughout the year | **Increase** of between 3°C to 5°C throughout the year | **Increase** of between 1°C to 1.5°C throughout the year | **Increase** of between 1°C to 2°C throughout the year | **Increase** of between 1°C to 2°C throughout the year |
| **Precipitation** *Wet season* | **Increase** in monthly precipitation up to 40 mm | **Increase** in monthly precipitation up to 40 mm | **Increase** in monthly precipitation up to 25 mm | **Increase** in monthly precipitation up to 75 mm (21%) | **Increase** in monthly precipitation up to 70 mm (14%) |
| *Dry season* | **Minor increase** in March–May and December. **Minor decreases** in Jan-Feb | Minor **decrease** in dry season precipitation | Minor **decrease** in dry season precipitation | **Increase** in monthly precipitation up to 70 mm (27%) | **Decrease** in monthly rainfall up to 3 mm/month (12%) |
| **Storms** | Large rainfall events will **increase** in size | Large rainfall events will **increase** in size | Large daily rainfall events will **increase** in size up to 50 mm | Large daily rainfall events will **increase** in size up to 40 mm | Large daily rainfall events will **increase** in size up to 20 mm |
| **Droughts**[23] | The pattern of agricultural drought will be **unchanged** | **No significant changes** in drought trends | Significant **increase** in the occurrence of agricultural drought conditions in Apr–May | Very **little change** in drought occurrence | **Increase** in the occurrence of agricultural drought conditions in April. |
| **Soil water availability** | **Minor impacts** on soil water availability | **Minor impacts** on soil water availability | N/A | **Decrease** during Dec–April. **Increase** up to 7% in May–July | Year-round **reduction** peaking at a 20% reduction in May |
| **SLR and flooding** | NA | NA | **Major increases** in flood depth and duration. | NA | NA |

23 The study used an agricultural definition of drought where a drought month occurs when the precipitation in that month is less than 50% of the potential evapotranspiration.

**Table 18: Climate projections for secondary priority provinces**

| | Sakon Nakhon | Champasak[24] | Kampong Thom[25] |
|---|---|---|---|
| **Daily maximum temperatures** | **Increase** of between 1.3°C to 2.7°C throughout the year | **Increase** of between 1.7°C to 3.7°C throughout the year | **Increase** of between 2.0°C to 4.0°C throughout the year |
| **Daily minimum temperatures** | **Increase** of between 0.8°C to 1.8°C throughout the year | **Increase** of between 0.8°C to 1.7°C throughout the year | **Increase** of between 0.9°C to 1.8°C throughout the year |
| **Precipitation**<br>*Wet season* | **Increase** in monthly precipitation up to 60 mm (21% increase) | **Increase** in monthly precipitation up to 50 mm (17% increase) | **Increase** in monthly precipitation up to 40 mm (18% increase) |
| *Dry season* | **Increase** up to 25 mm/month during March, April, May and Dec.<br>**Minor decreases** in Jan and Feb | **Increase** up to 8 mm/month (16% increase) during May and Dec.<br>**Minor decreases** during Jan to April | **Increase** up to 20 mm/month (13% increase) during May.<br>**Minor increase** during March and Dec.<br>**Minor decreases** during Jan, Feb April and Dec |
| **Storms** | Large rainfall events will **increase** in size | Large rainfall events will **increase** in size | Large rainfall events will **increase** in size |

24 There is a large elevation difference from the east to west of Champasak Province. The results provided in the table are for the hotter and dryer lower-elevation west side of the province. The cooler and warmer higher-elevation areas to the east of the province will experience a slightly less significant change in precipitation and a much more pronounced increase in temperature.

25 The projected increase in wet season precipitation is highly variable in Kampong Thom Province. The results provided in the table above are for a point in the south center of the province. It represents an average increase, areas to the west will see lower increases (as low as 7% increase) and areas to the east will see more significant increases in wet season precipitation (up to 14% increase).

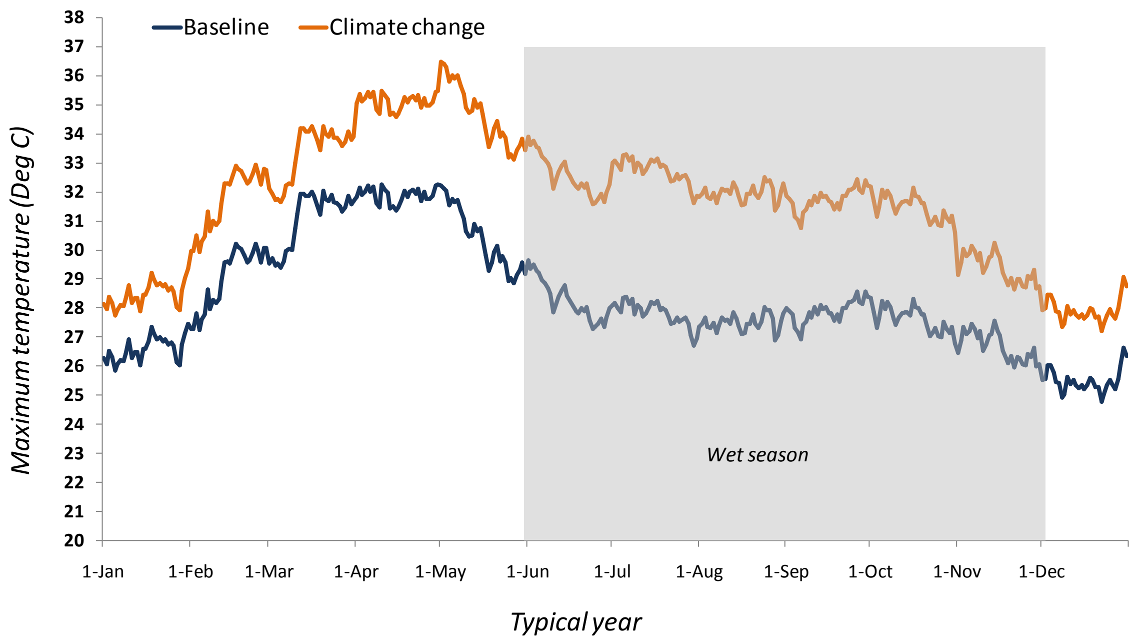
### 4.5.2 GIA LAI

**Gia Lai Province in the Vietnamese Central Highlands comprises upland areas of the Sesan Catchment and is projected to experience large increases in temperature with annual maximum temperatures rising by 8% to 11% by 2050.** The increases will occur throughout the year from a minimum increase of 1°C in January to a 4°C increase in July and August (Figure 4-31).

**Annual precipitation increases in the province are moderate** for the Mekong ranging between 5% and 8%. However the variability between the seasons may be more pronounced, increasing up to 11% during the wet season and decreasing by 3% to 10% during the dry season.

**Figure 4-31: Gia Lai annual time series of projected increases in daily maximum temperature:** *The solid blue line is the average of the GCMs for the baseline centered around 2000. The solid orange line is the climate change average of the GCMs*



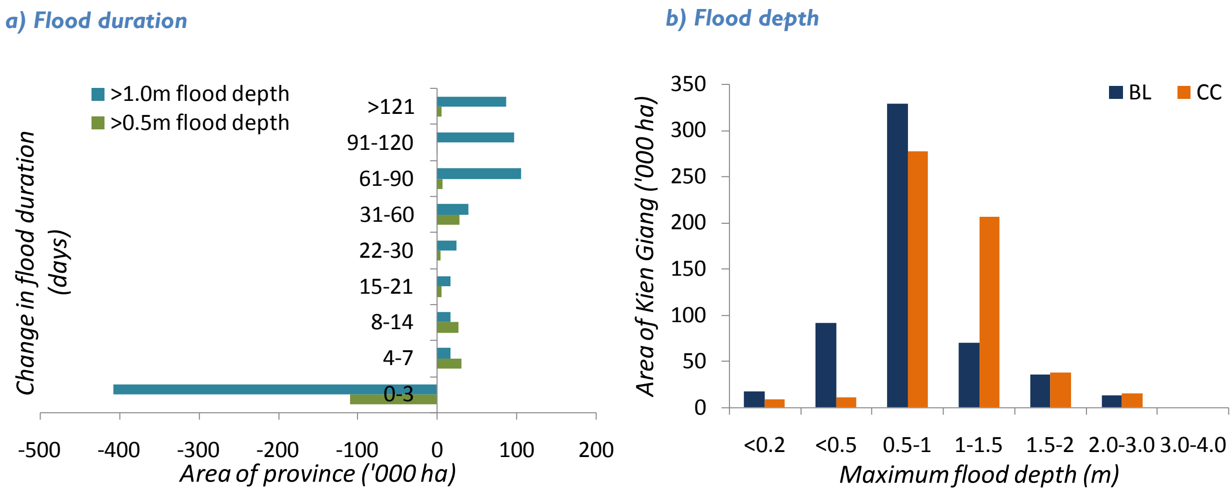



### 4.5.3 KIEN GIANG

**Sea level rise and flooding may cause drastic changes in the depth and duration of flooding in Kien Giang.** Under climate conditions during an average flood year over 400,000 ha that was previously rarely or never flooded to a depth of 1.0 m is projected to experience flooding of this depth for up to 121 days per year. Similarly an area of over 100,000 ha that was previously rarely or never flooded to a depth of 0.5 m will experience flooding of this depth. The maximum flood depths during an average year may also increase due to climate change. A total of 141,000 ha historically inundated up to depths of 1.0 m may be inundated by 1.0 m to 3.0 m by 2050 (Figure 4-32).

**Kien Giang is projected to experience relatively minor increases in precipitation and daily maximum temperature.** Annual precipitation will increase by 5% to 8% and daily maximum temperature increases across the province may range between 5% and 10%. This province was included in the priority provinces because of the impacts of sea level rise and flooding, not because of the projected increases in precipitation and temperature.

**Figure 4-32: Projected changes in flooding in Kien Giang Province for an average flood year and sea level rise of 0.3 m:** *a) Change in area of duration of floods of >1.0m and >0.5m depth in Kien Giang Province; and b) Baseline and climate change areas of maximum flood depths*



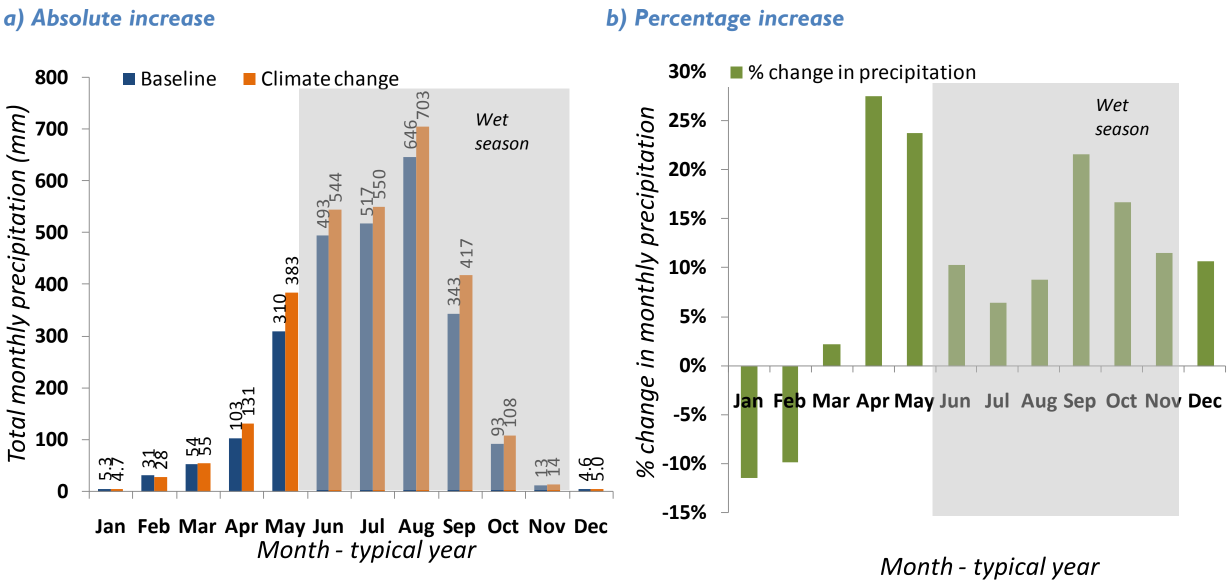

## 4.5.4 KHAMMOUAN

**Khammoun Province is projected to experience some of the largest increases in precipitation within the LMB with annual precipitation increasing by 8% to 18% by 2050.** The annual precipitation increases will be driven by large increases up to 25% of the monthly rainfall during April and May (30 mm and 70 mm increases, respectively) (Figure 4-33 a and b).

**Temperature increases will be mostly moderate across the province** (between 5% to 8%), except for a section in the northwest hills which will see increases in temperature up to 16% (2°C increase).

Khammouan Province is predominantly lowland except for a small section in the northwest next to the border with Ha Tinh province in Vietnam. This area steeply climbs to a very small section of upland on the border and therefore experiences slightly higher precipitation but lower temperatures.

**Figure 4-33: Khammouan projected increases in monthly precipitation:** a) absolute increase; and b) percentage increase

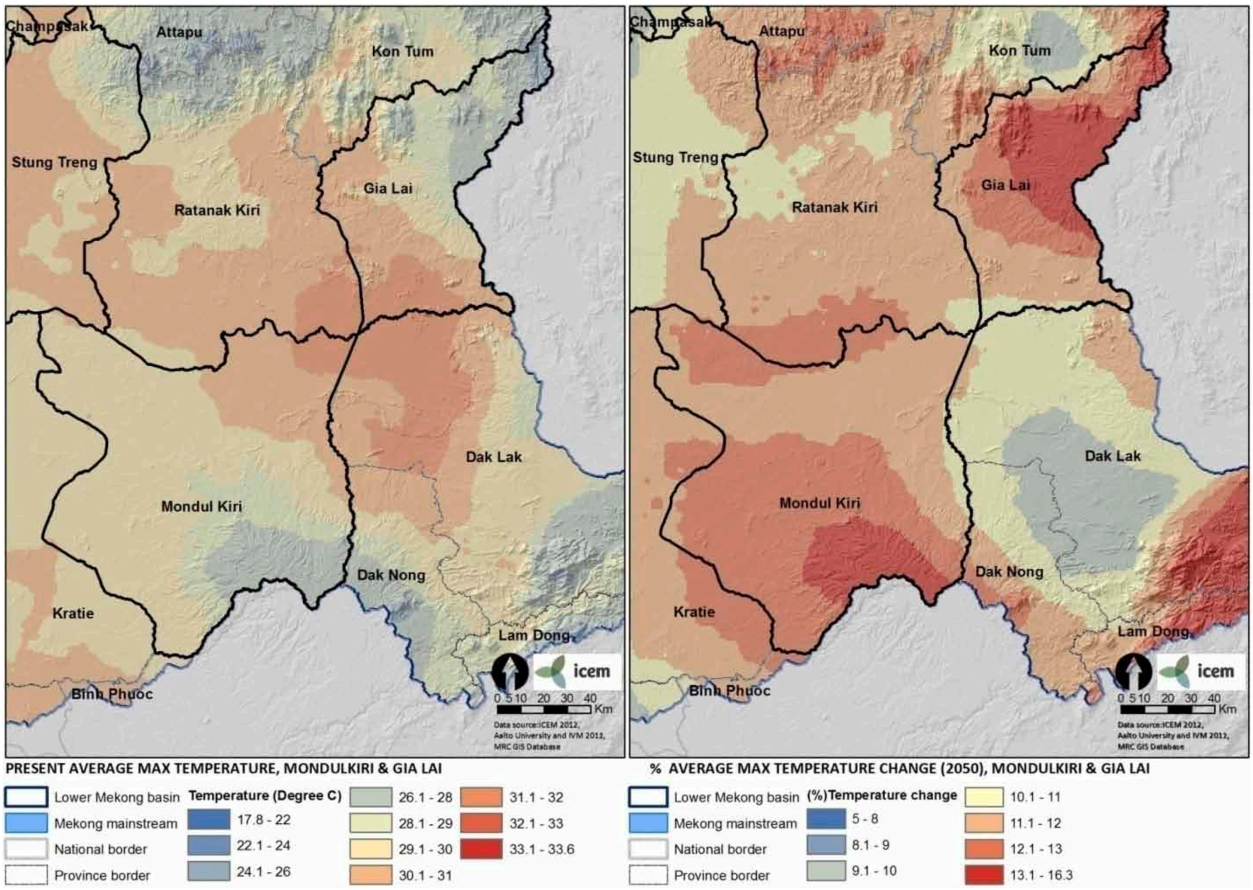


### 4.5.5 MONDULKIRI

**The highland area of Mondulkiri is projected to experience some of the largest increases in temperature within the LMB with annual maximum temperatures rising by 12% to 16% including increases over 5°C during April** (Figure 4-34).

Mondulkiri covers both midland and lowland areas of the Srepok catchment linking the upland areas within Vietnam to the broad Mekong floodplain expanse south of Kratie. The variation in elevation results in two comparable climate change regimes with the lowland areas being hotter and drier. It is the historically cooler highlands that are projected to experience the highest changes in temperature but by 2050 they will remain slightly cooler than the lowlands.

**Figure 4-34: Mondulkiri projected change in annual average daily maximum temperature**




**Precipitation increases in Mondulkiri are moderate** for the Mekong ranging between 5% and 8% increases by 2050. However the variability in seasons may become more pronounced as the precipitation increases by 11% during the wet season and decreases by 3% to 10% during the dry.

# 5 BASELINE AND IMPACT/VULNERABILITY ASSESSMENT

In climate change assessments of species and natural systems it is often the initial scoping and baseline phase that consumes most time. All else depends on the accuracy and detail of the data gathered to establish the science evidence base for later steps. A key task of the baseline assessment is to identify key issues and trends affecting the target species and systems, including past climate variability and extreme events. The main drivers and influences of change—apart from climate change—need to be identified. In the CAM method findings on those other drivers of change are set aside during the impact and vulnerability assessment stage and brought back for consideration when defining adaptation strategies. The baseline phase also includes the projection of climate changes and the definition of climate threat profiles for the target areas, species and systems.

Each of the five theme groups in the study conducted baseline assessments as a first step in the CAM impact and vulnerability assessments as outlined in Table 19 and described in this chapter.

**Table 19: Theme group baseline and vulnerability assessments in priority provinces**

| Theme group | Basin-wide and ecozone | **Primary priority provinces:** Chiang Rai, Gia Lai, Kien Giang, Khammouan and Mondulkiri | Secondary priority provinces |
|---|---|---|---|
| Agriculture | ▪ Hotspot ranking/scoping<br>▪ Baseline assessment and trend analysis<br>▪ Crop suitability analysis | ▪ Crop yield modeling<br>▪ CAM vulnerability assessment of key crop species | In Sakon Nakhon, Champasak and Kampong Thom:<br>▪ Crop yield modeling<br>▪ CAM vulnerability assessment of key species |
| Livestock | ▪ Hotspot ranking/scoping<br>▪ Baseline assessment and trend analysis<br>▪ CAM livestock database | CAM vulnerability assessment of key livestock species and systems | |
| NTFPs and CWRs | ▪ Hotspot ranking/scoping<br>▪ Baseline assessment and trend analysis<br>▪ CAM NTFP and CWR database | Species vulnerability assessment for key NTFP and CWR species | |
| Protected Areas | ▪ Hotspot ranking/scoping<br>▪ Baseline assessment and trend analysis<br>▪ CAM protected areas database | CAM vulnerability assessment for five hotspot protected area clusters and individual protected areas | CAM vulnerability assessment for Tonle Sap tropical grasslands |
| Aquaculture | ▪ Hotspot ranking/scoping<br>▪ Baseline assessment and trend analysis<br>▪ CAM aquaculture database | CAM vulnerability assessment for key aquaculture species located in the province | CAM vulnerability assessment and adaptation planning for 3 species in Strung Treng |
| Capture Fisheries | ▪ Hotspot ranking/scoping<br>▪ Baseline assessment and trend analysis<br>▪ CAM Fish Database<br>▪ Catchment level assessments to define fish species | CAM vulnerability assessment for key capture fisheries species located in the province | CAM vulnerability assessment and adaptation planning for 3 species in Strung Treng |
| Health and infrastructure | ▪ Hotspot ranking/scoping<br>▪ Baseline assessment and trend analysis | CAM vulnerability assessment for health and infrastructure in the province | |

## 5.1 AGRICULTURE

### 5.1.1 BASELINE OVERVIEW

In the LMB growing conditions for agriculture are diverse, from the mountainous areas of Lao PDR and the Central Highlands in Vietnam to the lowland plains of the delta in Cambodia and Vietnam. Farming systems range from traditional shifting agriculture dominated by upland rice to industrial plantations. Yet, similar patterns and trends can be highlighted across countries and ecological zones with the spread of commercial crops and the emergence of commercial agriculture supplementing and replacing subsistence rice-based systems.

**Rainfed agriculture is the main farming system in the LMB with rainfed rice the dominant crop, representing 75% of the agricultural area**. Other commercial crops such as maize, soya or cassava, with growing importance are mostly rainfed. The suitability range of crops is important with similar crops found across ecozones. Crop suitability and trends in crop production may change due to the impact of climate change. Average rainfall above 1,000 mm per year across the basin means that annual rainfall is not the primary constraint for agriculture. Instead, it is the un-predictability and variability of rainfall during the rainy season that can generate drought, water stress and low yields.

**In high- and mid-elevation ecozones, commercial agriculture is expanding into new areas.** After substantial growth in recent decades in the Central Highlands of Vietnam, rubber plantations, cassava, maize, and sugarcane are expanding into Lao PDR as key commercial crops in addition to lowland rice. Farming systems in upland zones are moving from traditional subsistence shifting cultivation to more commercial forms. In the Vietnamese Central Highlands and the Bolaven Plateau in Lao PDR, for example, significant areas are dedicated to Robusta coffee plantations.

**Low-elevation areas are dominated by lowland rainfed systems, sometimes with access to irrigation.** The cultivation of commercial crops began in northeast Thailand and then on Cambodia's plateau, beginning in the northwest provinces (Pailin, Oddar Meanchey, Bantheay Meanchey, Battambang) and now reaching eastern provinces (Siem Reap, Ratanakiri). In northeast Thailand, sugarcane remains important with rubber covering even larger areas, most recently in Cambodia with the expansion of smallholders and private concessions. Along the Mekong corridor in Lao PDR, similar commercialization is occurring using more inputs and mechanization under the influence of Thailand's agro-sector. Maize, cassava, sugarcane, soya, and rubber are the main crops cultivated together with rainfed rice.

**The Cambodian floodplain supports a diverse rice-based farming system, where the different cropping patterns for rice depend on flood duration and receding water.** In this ecozone, investments in agricultural intensification have developed or rehabilitated irrigation areas. Between 2001 and 2010, the harvested area of dry season rice increased by 5% per annum to 404,800 ha.

**The Mekong Delta is the most intensive rice growing region in the LMB, with triple rice cropping in the fresh water areas**. Triple rice cropping is found in areas protected from the flood and saline water intrusion. Fruit orchards and other crops such as sugarcane and pineapple are cultivated in specific areas of the delta, while rice-shrimp rotation is found in coastal areas where saline influence is significant.

This broad typology of farming systems across the ecozones of the LMB is summarized in Table 20.

**Table 20: Summary of agriculture production systems found across the ecozones**

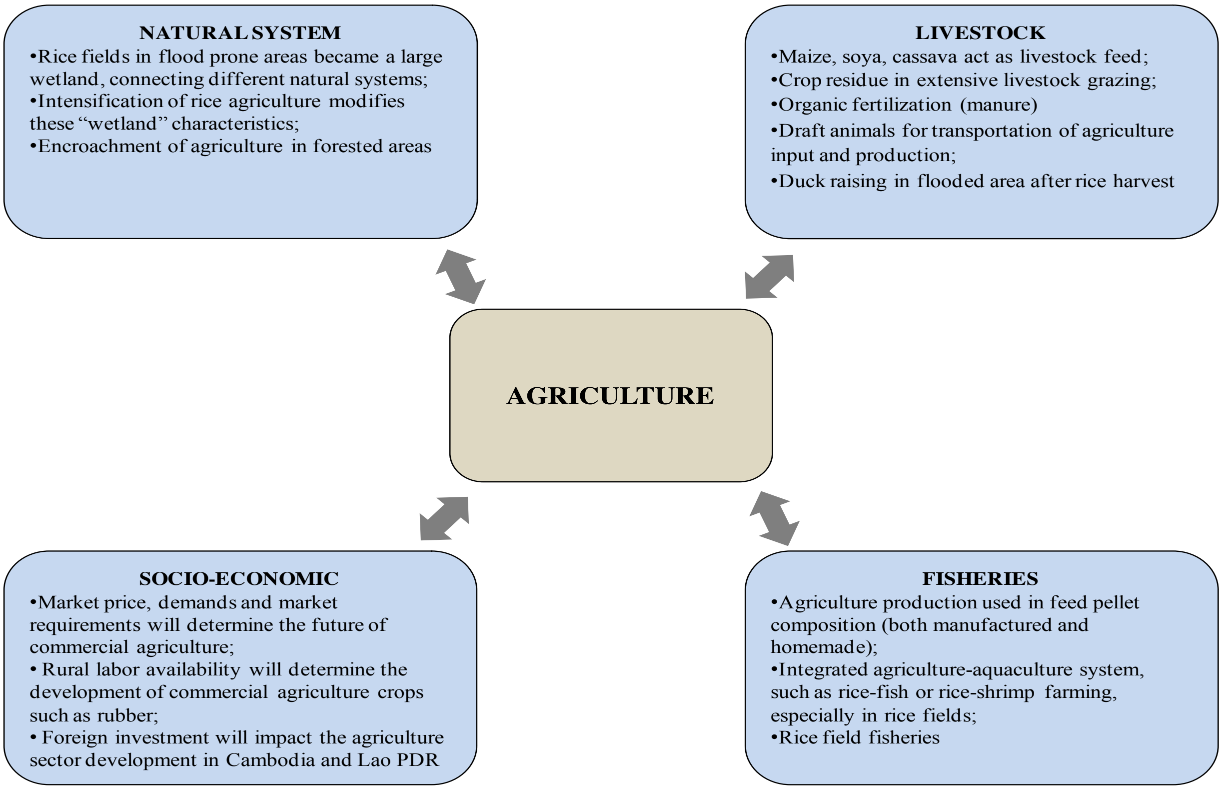
| Ecozone | Production systems | Farming strategy |
|---|---|---|
| **Floodplain and Mekong Delta** | Intensive rice culture, dry season irrigation and recession rice (double or triple rice crop) with additional vegetable crop production. Other commercial crops (e.g., maize, pineapple, sugarcane, cassava, and fruit trees) can replace rice crops | Smallholder – oriented towards commercial farming |
| **Low-elevation ecozones** | Rice-based production systems diversified with commercial crops (soya, maize, cassava, or sugarcane). Smallholders cultivating commercial crops and/or rainfed rice with or without supplementary irrigation, and contract farming or the concession of commercial crops (soya, maize, or rubber).<br>Increasing use of inputs and mechanization in commercial farms. Market-driven production systems | From subsistence farmers to increasing commercial small-scale and medium-scale farmers<br>Recent expansion of contract farming and industrial plantations |
| **Mid- and high-elevation ecozones** | Extensive swidden agriculture system based on upland rice farming, without inputs<br>Commercial farming by both large-scale concession (rubber, coffee) but also smallholder (rubber, coffee, cassava, rice, maize, and sugarcane), partially irrigated (coffee, rice, sugarcane), intensive use of inputs | Subsistence upland farming (swidden agriculture)<br>Commercial intensive farming in uplands (rubber, coffee and cassava)and rice, maize, and sugarcane in lowland |

Within the farming system, agriculture interacts with other sectors (Figure 5-1). Those interactions are more important for smallholder farms than they are in commercial plantation monoculture. Usually smallholder farms are a tight integration of agriculture, aquaculture, and natural systems. Interaction includes for example the provision of animal feed directly through use of crop residues and wild plants for livestock and aquaculture systems. Ducks are commonly raised on harvested rice fields on the floodplain and Mekong Delta. Livestock provides draft animal manure for organic fertilizers. Similar close integration is found with aquaculture and fisheries in rice fields.

Traditional rice fields are very productive wetlands capable of supporting diverse fauna and flora. However, intensification of rice production and techniques promoting alternate drying of rice fields along with increasing use of pesticides and herbicides affect wetland productivity and biodiversity.

From a socio-economic point of view, interactions with the agriculture sector are significant. Market rice, agriculture policy, international demand, and foreign investment increasingly shape the agriculture sector and will continue to have a great impact on the development of small- and large-scale commercial systems.

**Figure 5-1: Links and interaction of agriculture systems with other sectors**




### 5.1.2 CLIMATE SUITABILITY

The results of crop suitability modeling with climate change shows both positive and negative shifts for the crops tested across the LMB as summarized in Table 21. The rubber suitability map provided in Figure 5-2 shows suitability for rubber. Maps showing the results of suitability modeling results for all other target crops appear in the agriculture theme report.

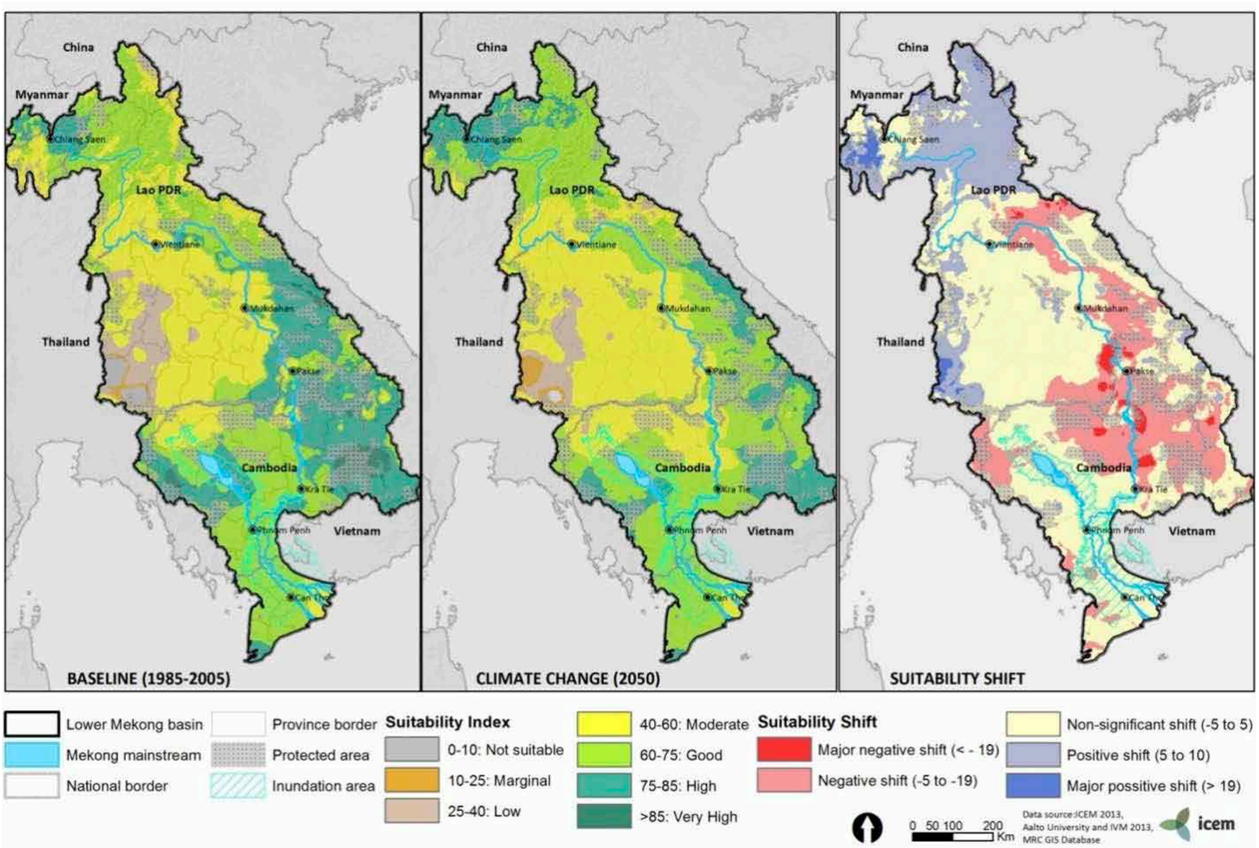
**Table 21: Summary of findings per crop and ecozone and relevance for current agro-system**

| | Main change in Suitability | Location | Ecozone | Example of changes |
|---|---|---|---|---|
| **Rubber** | Increased suitability due to increased precipitation | Northern Thailand (Chang Rai) and Northern Lao PDR (LouangNamtha, Phongsali; Oudomxai) | ▪ High-elevation moist broadleaf forest | 5,500 $km^2$ of increase suitability in Northern Thailand |
| | Increased suitability due to higher temperature | Northern Thailand (Chang Rai), Lao PDR (LoaungNamtha, Phongsali; Oudomxai), Central Highlands (Kom Tum) | ▪ High-elevation moist broadleaf forest ▪ Mid elevation moist broadleaf forest | |
| | Decreased suitability due to increased rainfall | Cambodia (Kratie, Preah Vihear) and Central and Southern Lao PDR (Champasack) and Chi Bun Basin In Northeast Thailand (Ubon Ratchatani) | ▪ Low-elevation dry broadleaf forest ▪ (Mid floodplain, wetland, lake) ▪ (Mid-elevation dry broadleaf forest) | 7,000 $km^2$ decreased suitability in Chi Bun basin |
| **Cassava** | Increased suitability due to higher temperature | High and mid elevation eco-zone (Northern Lao PDR in Louangprabang, Louangnamtha, Xayaburi and Central Highlands, Kontum) | ▪ High-elevation moist broadleaf forest ▪ (Low-mid elevation moist broadleaf forest) | 14,000$km^2$ of increased suitability in Northern Lao PDR |
| | Decreased suitability due to higher temperature | Low elevation eco-zones (Lao PDR, Cambodia and Central Highlands) | ▪ Low-elevation dry broadleaf forest ▪ Low-elevation moist broadleaf forest | 25,000 $km^2$ in Cambodia shift to lower suitability |
| | Decreased suitability due to increased precipitation | Lao PDR in Champasack and Cambodia - Stung Treng, Preah Vihear, Battambang; and Central Highlands - Gia Lai | ▪ Mid-elevation dry broadleaf forest ▪ Low-elevation dry broadleaf forest ▪ Low-elevation moist broadleaf forest ▪ (Floodplain, wetland, lake) | |
| | Increased suitability due to increased precipitation | Northern Thailand (Chang Mai, Chang Rai) | ▪ Mid-elevation dry broadleaf forest ▪ High-elevation moist broadleaf forest ▪ Low-mid elevation moist broadleaf forest | 900 km2 change to high and very high suitability |
| **Maize** | Decreased suitability due to increased precipitation | Louangnamtha; Vientiane, Khamouane and Phongsaly province (Lao PDR),DakLak in Central Highlands (Vietnam) | ▪ Low-mid elevation moist broadleaf forest ▪ High-elevation moist broadleaf forest ▪ Mid-elevation dry broadleaf forest | 5,000 $km^2$ shift to lower suitability in Dak Lak province |
| **Soya** | Decreased suitability due to increased precipitation | Kampong Chhnang, Battambang, PreahVihear, Pursat, Kampong Cham Siem Reap, Kratie and Kampong Thom (Cambodia) | ▪ Low-elevation dry broadleaf forest ▪ Low-mid elevation moist broadleaf forest | More than 60,000 $km^2$ will experience decreased suitability for soybeans, due to increases in precipitation. |
| **Robusta Coffee** | Increased suitability due to higher temperature | Chang Mai, Chang Rai, North Lao PDR | ▪ High-elevation moist broadleaf forest ▪ Mid-elevation dry broadleaf forest | 2,500$km^2$ in Chiang Mai and Chiang Rai will shift to higher suitability |
| | Increased suitability due to increased precipitations | Chang Mai, Chang Rai, North Lao PDR | ▪ High-elevation moist broadleaf forest ▪ Mid-elevation dry broadleaf forest | |
| | Decreased suitability due to higher rainfall and temperature | Lao PDR (Champasack and Attapeu) and Western Cambodia (Mondulkiri, Ratanakiri) and Central Highlands | ▪ Mid-elevation dry broadleaf forest ▪ Low-elevation dry | 1,800 km2 will shift to lower suitability in Champasack |

**Rubber, Robusta coffee and rice experience positive shifts in various areas of the high- and mid-elevation ecozones.** Altitude shifts in climatic conditions due to increase of temperature are also important for rubber cultivation and new areas suitable for industrial plantations will become available by 2050.

**Yet, rubber plantations experience large negative shifts in production area in Western Cambodia, the Vietnamese Central Highlands** and in recently planted areas like Champasak Province in Lao PDR due either to increase in rainfall or prolonged drought. Those changes in climate suitability are relevant for future planning. Similarly, future coffee plantations in Mondulkiri Province of Cambodia will be affected by changes in rainfall and temperature—future coffee plantations in this province might need to be reconsidered.

**Figure 5-2: Rubber suitability in the Lower Mekong Basin – results of LUSET modeling**




**Soya, maize, cassava, and coffee will experience decreases in suitability in specific locations due to increased precipitation**, in some cases exceeding suitable growing conditions altogether. Similarly, in some parts of the LMB an increase in temperature will reduce the suitability for cassava, while it will allow for higher suitability in higher altitudes where current cultivation is limited by low temperature.

Rainfed rice culture is too diverse to assess in detail. However, the study shows that **increased precipitation in the rainy season will increase the suitability for lowland rainfed rice culture**. The model does not take into account extensive flooding or flash floods related to projected increased rainfall which past experience has shown to be extremely destructive of rice and other crops.

### 5.1.3 MAIZE AND RICE YIELD

**Yield modeling for rice and maize shows a general decrease in yield compared to the current situation in the hotspot provinces** (Table 22). Changes in yield are variable but typically will decrease by 2050 due to higher temperatures during the crop season as plants will be vulnerable to increasing temperatures.

Rainfed rice is the most important crop in the LMB. Increases in diurnal temperatures can reduce rice yields (Welch et al. 2010). **A decrease in average rice yields of just a few percent per hectare would have dramatic impact on LMB food security and food production.**

**Multiple, interacting climate parameters will significantly influence rice yield.** Other areas such as northeast Thailand can expect an increase in rainfed rice yield by 2050. Yield increases are attributed to $CO_2$ fertilization and higher rainfall. The negative impact related to the increase of temperature is offset by $CO_2$ fertilization. The negative effects of $CO_2$ fertilization on grain protein shown in recent research have not been taken into account in this modeling.[26]

**By 2050, maize yield across the hotspot provinces will decrease by 3% to 12% due to increased rainfall or temperature** (Table 22). Gia Lai in Vietnam is expected to be particularly hard hit with reductions in both rainfed rice and maize yields of 12.6% and 12.1% respectively by 2050.

**The yield gap resulting from different climatic condition could be addressed with improved crop management.** While the modeling results quantify some of the threats of climate change, the study did not consider changes in agricultural management practices, such as modifying the fertilization level. Planting date and growing period will have an important impact on rice yield and are the most influential variables (Mainuddin et al. 2010). Shifting the calendar for planting and harvesting dates, using early maturing varieties and increasing fertilizer (or improving their use-efficiency) could reduce the yield gap due to climate change.

**Table 22: Crop yield modeling for rainfed rice and maize: baseline and 2050**

| Province | Rainfed rice baseline (ton/ha) | Change by 2050 (%) | Potential loss or gain for rainfed rice (tons/year/province) | Maize baseline (ton/ha) | Change by 2050 (%) | Potential loss or gain for maize (tons/year/province) |
|---|---|---|---|---|---|---|
| Chiang Rai | 3.4 | -4.8 | -30,000 | 4.22 | -3.13 | -6,500 |
| Sakon Nakhon | 2.1 | 4.6 | + 27,000 | | | |
| Khammouan | 3.4 | -0.1 | n.s | 4.74 | -5.03 | n.s |
| Champasak | 2.9 | -5.6 | -11,000 | 5.08 | -5.55 | -2,000 |
| Gia Lai | 3.3 | -12.6 | -20,000 | 3.54 | -12.09 | -24,000 |
| Mondulkiri | 2.1 | -3.0 | -1,114 | | | - |
| Kampong Thom | 2.2 | -3.6 | -15,000 | 3.06 | -5.97 | n.s |

*n.s: no significant change in production (i.e., below 1,000 tons)*

### 5.1.4 ASSESSMENT OF CROP VULNERABILITY BY HOTSPOT

For each hotspot province, the main crops were identified and vulnerability assessments conducted based on crop physiology and climate modeling. Only high vulnerability results for each crop in each

[26] Schellnhuber, Hans Joachim et al. 2013. *Turn down the heat: climate extremes, regional impacts, and the case for resilience.* Washington DC; World Bank.

hotspot are presented here (Tables 23 and 24). The full results are presented in the agricultural theme report.

**Increased temperature was found to be a common threat across the basin. Lowland rainfed rice and irrigated rice will experience reduced yields due to temperatures higher than 35°C during the growing stage.**[27] The increase of the minimum temperature during the night will also affect rice yield. In the Mekong Delta, it was found that rice in the dry season will be highly vulnerable to increased temperature. Saline water intrusion and sea level rise will affect both irrigated and rainfed rice, with water quality constraints, shorter growth period, and higher flood level and duration.

Increased water consumption due to higher temperatures in late dry season or during droughts may be an issue that generates conflict among competing water users.

**Soya, rice, maize, and coffee will be vulnerable to increased rainfall.** Increased rainfall will affect lowland soils with low drainage capacity for those crops that do not tolerate water logging. Increased rainfall will also affect the yield of those crops if excessive during the harvest and post-harvest period leading to more losses. Water logging and increases in intensity of rainfall during those critical periods are likely in 2050.

Increase in incidence of pest and fungal diseases due to increases in rainfall and temperature are likely but were was not assessed in this study due to the lack of data. Disease is a significant cause of reduced productivity in coffee plantations for example. In 2013, the Tay Nguyen (Central Highlands) Agriculture and Forestry Science and Technical Institute developed 21 new coffee varieties that are disease resistant and have high yields. The new coffee varieties—11 Robusta and 10 Arabica variations—are highly resistant to coffee rust disease caused by the *Hemileia vastatrix* fungus, which has devastated coffee plants in the Central Highlands.

**Table 23: High vulnerability of crops to changes in temperature and precipitations in the 8 hotspots**

| Crops | Main Vulnerability | Hotspot |
|---|---|---|
| Rainfed Rice | Increased temperature | Chiang Rai, Sakon Nakhon, Khammouan, Champasak, Kampong Thom |
| Irrigated Rice | Increased temperature | Champasak, Kampong Thom, Kien Giang |
| Maize | Increased precipitation | Khammouan, Champasak |
| Cassava | Increased precipitation | Sakon Nakhon; Khammouan, Champasak, Mondulkiri |
| Soya | Increased temperature | Kampong Thom |
| | Increased precipitation | Mondulkiri |
| Rubber | Increased temperature | Chiang Rai; Sakon Nakhon |
| Coffee | Increased precipitation | Champasak |
| | Increased temperature | Gia Lai |
| Litchi | Increase temperature | Chiang Rai |

**Increase of temperature alone will also affect soya, maize, and cassava but their vulnerability to this one parameter is considered medium. However the combined effects of increased temperature and excessive rainfall could induce a significant yield drop in those crops**. Sugarcane is more resistant to high temperatures, and it is less vulnerable compared to rice or cassava. Sugarcane can endure a certain level of water logging. Industrial plantations of coffee and rubber will also face increased temperatures with maximum temperatures above the optimal range and in some cases will require an altitude shift in plantations if yields are to

[27]The highest vulnerability is experienced during anthesis and ripening stages, where the rice plant has a low tolerance for temperatures above 35°C.

be maintained. In the case of the Bolaven Plateau, the projected increased precipitation may affect coffee plantations. The potential for increase of pest and fungi with increased temperature and rainfall in coffee plantations as well as for other crops has not been assessed due to lack of data.

Increase rainfall especially in northeast Thailand will limit the water stress in rainfed systems. The climate modeling, looking at monthly rainfall and temperature data, does not show increases in dry spells in the rainy season, one of the main threats for rainfed crops and especially for rice.

**Table 24: High vulnerability of crops to extreme climate change events in 8 provincial hotspots**

| Crops | High vulnerability to storm and flash flood | High vulnerability to flood |
|---|---|---|
| Rainfed Rice | Khammouan, Champasak, Mondulkiri | Khammouan, Kampong Thom |
| Maize | Khammouan, Gia Lai | Khammouan |
| Cassava | Khammouan, Champasak, Mondulkiri, Gia Lai | Khammouan, Sakon Nakhon, Kampong Thom |
| Sugarcane | Khammouan | Khammouan |
| Soya | Mondulkiri | Kampong Thom |
| Robusta Coffee | Champasak, Gia Lai | |

**The higher incidence of extreme events such as storms and heavy rainfall will increase the vulnerability of the most farming ecosystems in the region.** The lowlands will experience higher incidence of floods and flash floods (Table 24). In uplands, the combination of climate changes with destructive agriculture practices and lack of soil conservation considerations will lead to an increase in soil erosion and loss of fertility. This threat is exacerbated in the case of cassava culture. Already loss of fertility is observed in the Vietnamese Central Highlands when cultivation occurs on steep land.

**Impact and vulnerability to extreme climatic events will bring increased damage and crop losses, possibly more serious than decreases in yields due to higher temperature or rainfall that can be addressed through improved crop management. At the basin level, subsistence production systems such as upland shifting cultivation or smallholder rice farmers are vulnerable**—although upland farmers normally cultivate a diversity of crops and use a diversity of natural system services and products that can provide safety nets at times of stress.

**Farmers involved in commercial crop cultivation are also vulnerable**—extensively cultivating a few cash crops may reduce options in response to climate stresses. For example, the cassava sector is supported by a large number of smallholders who would be deeply impacted by the high vulnerability of cassava culture.

Other crops such as soya, sugarcane, maize, and perennial plantation require more investment and capacity and are therefore cultivated by the more established farmers at medium-scale. However, a drop in production of those crops, will still affect the poorest, including the landless farmers, by reducing wage labor opportunities and other job opportunities within the value chain.

**Areas newly planted with rubber in Cambodia and in Southern Lao PDR are expected to be unsuitable for those crops by 2050.** Similar conclusions can be drawn for future coffee plantations in eastern Cambodia. Development of commercial agriculture with cassava, soya, and maize was found vulnerable to increases in rainfall and incidence of storms, floods, and flash floods in several hotspots across the LMB. For example, development of cassava, soya, and maize culture in the Mekong corridor in Lao PDR could be vulnerable in the near future—presently those crops are expanding and re-shaping the agricultural landscape of this region.

Future adaptation strategies will need to improve the overall adaptive capacity of farmers and not just address a specific threat to a specific crop. An approach is needed that acknowledges the complexity of farming systems with all components and the cumulative effects of multiple climate change threats as well as addressing the vulnerability to extreme climatic events.

## 5.2 LIVESTOCK

### 5.2.1 LIVESTOCK BASELINE OVERVIEW

Livestock production systems in the LMB can be placed on a spectrum ranging from "traditional" smallholder livestock "keeping" systems to large highly-productive commercial enterprises. The general descriptions provided below broadly encompass all current livestock production in the LMB:

**"Traditional" small-scale, low-intensity, low-input, and low-output systems, typically raising stock of local genetics and with limited market orientation:** While there is some variation between species, these systems contribute well over 90% of the total numbers of producers in the LMB, and over 50% of total production (Knips 2004).

Typically, bovines are raised individually or in small herds of under five. Pigs may be unpenned or confined, with herds of one or two sows and/or between two and ten fatteners. Chickens are raised in flocks of mixed ages, naturally mating with between 10 and 30 mature birds. Vaccination rates are low. Stock perform poorly against conventional performance indicators such as reproduction rates and feed efficiency, and daily gain and offtake rates are low (Maclean 2006). Stock fulfill multiple functions including supporting other household livelihood generation mechanisms such as cropping; they also provide a form of savings, a short-term cash source through occasional sales, and they contribute to social status (FAO-AGAL 2005). In these systems, livestock are important contributors to food security both directly, through consumption of their products, and indirectly through income from occasional sales (Simraks 1998).

Traditional systems are found throughout the LMB but are most prominent in more remote locations with less access to input and output markets, but greater access to communal and protected land (Cocks et al. 2004, Luthi 2007).

**Traditional systems dominate the higher-elevation forested and more sloping ecozones in the LMB and are associated with low-income households:** In many instances "traditional" animal-raising is associated with vulnerable groups and vulnerable household members, particularly the raising of small stock. Traditional production systems require low labor input allowing persons who are less able to work in the fields or off-farm, due to other household commitments or physical constraints for example, to contribute to household livelihoods. Women, the elderly, and children are often responsible for household livestock providing these persons with an important source of cash income and increasing social standing both within the household and wider community.

**Commercial enterprises employing higher-pressure husbandry practices and investing significantly more into inputs:** Stock is raised for income generation through sales of meat, milk, and/or eggs. In small- and medium-scale commercial systems livestock frequently constitute the main source of household income. The scale of commercially-oriented operations in the region ranges widely within and between species; from relatively small landless peri-urban units to large-scale vertically integrated companies. Though significantly less in terms of total farm numbers, commercial production volumes are relatively important and increasing, particularly for monogastrics and regional dairy production (FAO 2011). Usually, these systems supply urban markets. Commercial production is associated with local environmental concerns particularly in the more densely populated Vietnamese Delta and surrounding areas.

Small- and medium-scale commercial monogastric systems (pigs and poultry) show significant variation. For the purposes of this assessment they are defined as household owned, commercially oriented and confined pig and poultry production units. Poultry units categorized in this manner rear total head numbering less than 5,000, buying in chicks or incubating mechanically and purchasing completely processed feeds. Pig units use processed feeds and rear less than 200 fatteners and/or less than 30 sows.

**Commercial production systems are becoming increasingly prominent in the LMB where they tend to be concentrated in the low-lying ecozones:** Commercial production, at various scales, is most prominent in Vietnam, in northeastern Thailand, and is becoming increasingly prevalent near Phnom Penh and Battambang in Cambodia (Knips 2004, Indochina Research Ltd & Phil Psilos 2007). By 2020, demand for each of the major livestock-derived products in basin countries is projected to increase by 150% to 300% driven by increasing incomes and urbanization, a trend likely to continue towards 2050 (FAO 2011, Jabbar et al. 2010, Knips 2004). Commercial systems are associated with higher income households because of the higher capital investment required, greater production costs, and greater risk associated with loss and/or market fluctuations. It is rare for more commercially-oriented production to be undertaken by poor and vulnerable households or household members.

### 5.2.2 VULNERABILITY ASSESSMENT

#### 5.2.2.1 Summary of climate change threat vulnerability assessments

Expert judgment was used in the application of the CAM methodology to assess the level of vulnerability of each livestock system to specific climate change threats. Threats that were considered include temperature change, precipitation change, change in soil water availability, and changes in frequency and intensity of drought, flooding, and storms. In the livestock theme report these threats were each considered at provincial level where exposure to specific threats varied considerably. The summary provided here (Table 25 and 26) considers livestock systems in the LMB generally.

Table 25: Vulnerability assessment results for livestock systems

| System | Impact | Adaptive capacity | Vulnerability |
|---|---|---|---|
| **Smallholder cattle/buffalo** | Low | Low | ***Medium*** |
| **Dairy/large commercial** | Very high | High | ***High*** |
| **Small commercial pig** | High | Medium | ***High*** |
| **Smallholder low-input pig** | Low | Low | ***Medium*** |
| **Small commercial chicken** | Very high | Low | ***Very high*** |
| **Scavenging chicken** | Low | Low | ***Medium*** |
| **Field running layer duck** | Very low | Low | ***Low*** |

Table 26: Vulnerability assessment results for wild livestock systems

| System | Impact | Adaptive capacity | Vulnerability |
|---|---|---|---|
| **Banteng (esp. Mondulkiri)** | Low | Very low | ***Medium*** |
| **Eld's Deer (esp. Mondulkiri)** | Low | Very low | ***Medium*** |
| ***Sus Scrofa*** | Very low | Low | ***Low*** |
| **Wild Poultry** | Very low | Low | ***Low*** |

**Small- and medium-scale commercial operations are most vulnerable and have limited capacity to adapt.** The presence of commercial livestock production units has increased dramatically in recent decades, a trend highly likely to continue. The increase in commercial units is associated with an increase in the use of higher performance genetics and higher productivity management practices such as heightened stocking rates. High-performance breeds managed in high-density systems will be negatively affected by expected climate changes. Ambient temperature increases of up to 5°C, predicted for parts of the LMB, will reduce productive performance and increase behavioral problems, morbidity and mortality in the majority of small- to medium-scale commercial units without investment in cooling systems (Forman et al. 2008); investments that are typically beyond the reach of these producers. Productivity losses and increased mortality rates, particularly among young and immuno-compromised stock will negatively affect farmer incomes and may increase prices of livestock derived products, or drive increasing demand for imported products.

**Higher temperatures will have little measureable effect on individual animals in 'traditional' systems but multiplied across villages to regional level the impacts may be significant.** Traditional systems rear hardier local breeds and crossbreds with greater thermal tolerance such as *Bos indicus* cattle breeds, which are raised throughout the region primarily for draft (Hansen 2004, Maclean 2006). Though loss of productivity due to temperature increases is unlikely to be noticed on an individual basis, it is probable that draft animal fatigue (due to thermal stress/reduced feed intake) will reduce household incomes directly by limiting ability to work for hire and by reduced working life; and indirectly through impacts on other livelihood generating mechanisms. Among other species, reduced weight gain and laying rates may occur but the existing low offtake rates in traditional systems make estimation of losses difficult.

Though it is not possible to quantify changes in competitiveness and productive outputs associated with predicted climate changes to 2050 it is reasonable to describe trends and suggest likely impacts on the subsector.

#### 5.2.2.2 General productivity

**Temperatures above the upper critical value for specific animals will impact productivity and increase behavioral problems in intensely stocked systems**. This effect will be most notable among poultry and pigs housed in higher stocking densities in more commercially oriented systems, most prominent in low lying areas of the LMB (The Pig Site 2008). Stock will reduce their feed intake with higher temperatures, reducing liveweight gain and increasing time to slaughter weight. For example, in intensive pig systems, for each 1°C increase above approximately 30°C, a 5% reduction in voluntary feed intake can be expected. Sudden changes will have even greater impacts on stock health and productivity. More densely-stocked commercial poultry will experience comparable reductions in weight gain, egg weights, and eggs and hens per year. High stocking-rate pig and poultry systems will likely experience more behavioral problems, negatively affecting productivity and making management more difficult while increasing risks of infection through reduced immune responses. However, with all species the effects of increased temperature must be considered in relation to housing, in particular bedding but also humidity, the animal's thermal history, feeding rate, stocking rates, weight, age, sex, and genotype.

#### 5.2.2.3 Nutrition

**Climatic changes will likely affect the availability and price of local feed sources and ingredients which will have significant impacts on smallholders.** Drier dry seasons will likely increase the length and severity of low feed periods for grazing stock and those fed predominantly on local raw feeds—systems already stressed with stock scoring low on body condition. The need for good feed preservation systems will increase—greater use of preserved feeds risks exacerbating the negative effects of mycotoxins (aflatoxins in particular), already a significant constraint to many production systems. Aside from direct impacts on growth rates and reproductive performance, undernourishment also reduces livestock resilience to stress and disease challenges. Larger producers more closely tied to global commodity prices will be affected differently.

### 5.2.2.4 Animal health

**Negative impacts on feed availability caused by drought and flooding will reduce stock condition and resilience to disease.** Immunity is reduced by poor body condition and the risk of physical injury is increased potentially leading to infections among other health and production related issues. Further, drought and floods often lead to rapid stock sales as a household coping mechanism, increasing stock movement and mixing in the affected areas, which ultimately increases the risk of disease outbreaks. Disease challenges will be further increased by stress from transportation, change of diet, unfamiliar environmental conditions, and by stock condition.

**The quantity and quality of disease vector breeding sites will be altered by changes in the environment, particularly water availability.** For example greater climatic variability may include unseasonable rainfall in some areas, increasing stagnant water and increasing the availability of breeding grounds for mosquitoes; and the need for greater feed preservation and storage may encourage rodent problems. While pathogens vary widely in their temperature tolerances, spatial and temporal shifts in disease patterns have been well documented in the past and can be expected to increase with predicted climate changes and associated seasonal variation. Important disease vectors in the region include arthropods (mosquitoes, flies, and ticks) and rodents.

**Changing weather systems will influence the likelihood of pathogen transmission through fomites.** Wetter weather will increase the likelihood of disease transmission through mud, for example, increasing the importance of fundamental biosecurity measures such as cleaning and disinfection, quarantining, disposal of dead animals, and control of on- and off-farm traffic.

**Wetter wet seasons are likely to exacerbate current internal and external parasite problems.** Nematode infections are a common constraint to livestock production in the LMB. Parasitic infestation is usually seasonal and associated with the wetter conditions, which are expected to increase.

### 5.2.2.5 Extreme events – flooding, drought, storms

**Increased frequency and intensity of extreme events will have negative impacts on livestock.** Livestock may be lost due to extreme weather events. Flash flooding, for example, claims significant numbers in the region annually. Indirect impacts through malnutrition during and post droughts and slow-onset flooding affect huge numbers livestock producers. Two-thirds of affected livestock owners lost stock as a direct result of the September–October 2011 floods in Cambodia (FAO-WFP 2012). Further, increased stock movement and mixing associated with extreme events will increase the risk of disease outbreaks.

**Lethal effects of temperature extremes would be unlikely in most of the region; however, 60,000 cattles and buffaloes were estimated to have been lost in northern mountainous areas during the 2008 cold snap** (MRC 2010). Cold snaps in 2011 caused significant losses of poultry and pigs, particularly young stock. Climate change is expected to increase weather extremes, for example, sudden extremes in temperature may become more common which will result in increased thermal stress on stock in naturally ventilated buildings and will exacerbate stress related health and welfare issues and result in losses in productivity.

## 5.3 NATURAL SYSTEMS – NTFPS AND CWRS

### 5.3.1 NTFP AND CWR BASELINE OVERVIEW

**NTFPs make a significant contribution to national and local economies in the region and can make up over 30% of the income of individual farming families**. For example in 2007, the contribution of NTFPs was about 9% of total GDP of Lao PDR, including both cash income and non-cash income values. In some years, the seeds from false cardamom from Lao PDR are the second most valuable agricultural export commodity after coffee. In other years the export of malva nuts may exceed that of cardamom. NTFPs are essential for food security, medical remedies, fiber, and furniture and also provide resins and essential oils—the raw materials for pharmaceuticals, fragrances and other chemicals. Pressures on land and natural resources have meant that the only remaining sources for these natural products are protected areas. There is a strong financial incentive for sustainable management of this resource. NTFPs may be collected exclusively from wild sources, but there is a trend for valuable species to be cultivated or even domesticated, especially when species have an important export value.

This study of the potential climate change vulnerabilities and impacts on NTFPs and CWRs highlights the considerable variation expected between the different types of plants and animals and between the different locations within the LMB. The species considered are examples and not representatives of the type because other plant or invertebrate species may have very different vulnerabilities to climate change. Also many of the species considered have closely associated species or sub-species that are found in different parts of the basin adapted to the varied conditions. There may be some species or sub-species out there which have greater resilience than those described and which could be used for replacement as conditions in one area become too hostile for survival of the species described.

The ecological requirements of NTFPs and CWRs are complex. **All the species considered grow in forest or wetland plant assemblages and often depend on symbioses, synergies, and interactions with the other flora and fauna in these assemblages (thus ecosystems as well as complementary species climate change assessments are needed)**, for example:

- Fungi are pervasive throughout forest ecosystems. The natural cycle of growth, death, and decay of all species depends upon the functioning of fungi. Many fungi have close associations with specific tree or plant species, e.g., the fungus species *Russula virescens* has associations with trees in the family Fagaceae. Wild rice species are also associated with certain endophytic fungi which contribute to their growth and survival.
- Earthworms are essential for ecosystem functioning, breaking down dead plant materials, and releasing nutrients so that they are available for the next generation of plants in the forest. Earthworms have been considered separately here.
- Pollinators such as bees, bats and birds are very important and many plant species have evolved specific mechanisms to attract pollinators to their flowers. One of the most important species of bees, *Apis dorsata*, has been considered in its own right, but the critical interactions with plants such as orchids, cardamom, and many tree species has not been considered. The impacts of climate change on pollinators would be cumulative—as pollinators decrease in numbers, so the

potential for plants to be pollinated decreases. Eventually a threshold might be reached where the plant is no longer pollinated and dies out.

- The plants in their natural habitats are generally tolerant and resilient of disease or insect infestations, but if stressed (e.g., by rising temperatures or drought, or by loss of natural habitat) disease and insect attack may become more severe, leading to loss of that species. Increasing temperatures or increased moisture in the air at certain times of year may enhance the rate of spread of the disease or populations of attacking insects.

**Unlike domesticated crops, which are designed and grown in relative monocultures and in fairly or very exposed situations (e.g., open fields), NTFPs and CWRs generally live and grow in complex forest or wetland ecosystems.**[28] Generally, they are relatively protected. False cardamom, *Amomum spp*, for example, requires at least 50% forest cover or shade in order to thrive. The climbers, e.g., *Dioscorea hispida,* require other trees to grow up on and support them in the forest. On the other hand, plants such as paper mulberry, *Broussonetia papyrifera*, prefer to grow in open spaces within the forest caused by fallen trees, or at forest edges and where the forest has been cleared.

Forested areas moderate extremes in temperature and maintain a higher internal humidity than open fields of crops. Forests provide "refuges" against the extremes of temperature and drought. When forest cover and integrity is lost—as a result of logging, clearance, and over harvesting, for example—then the protection it offers decreases, and NTFP and CWR species are less able to cope with the stresses of climate change.

Some species will survive in more exposed situations and cultivated landscapes. These species are generally more hardy and able to cope with the exposed conditions and with extremes of climate. For example, wetland plants such as *Sesbania* may grow opportunistically in small ponds and roadside ditches and honey bees, red ants, and earthworms are all able to exist in cultivated landscapes if not subjected to agrochemicals.

**Many NTFPs and CWRs are well-adapted to climate extremes if undisturbed by other influences.** In their natural environment, most species have clear seasonal patterns, especially in the climatic conditions of the LMB where there is a marked distinction between wet and dry seasons. They are well-adapted to the dry season, when many species go into relative hibernation, shed their leaves, store up food sources in tubers, or aestivate (earthworms) or migrate (honey bees). They can largely withstand the extremes of drought and the lowering of soil moisture availability at the end of the dry season. Often the seeds that they produce can survive several years of dormancy, which allows them to wait for the best conditions before they germinate. Fungi are excellent examples of this strategy; they can survive these periods of extreme climate and take advantage of the climate variability to grow and reproduce when the conditions are less extreme. A number of species, especially the grasses and herbs, climbers, and aquatic plants have vegetative reproduction and can grow from the rootstock and rhizomes in addition to producing seeds. This means that they can continue to multiply and spread when seed production is limited.

[28] Some NTFPs and CWRs are also found growing along edges of fields, roadsides and ponds. These may be remnants of such assemblages or are the hardy or pioneer species that can survive changed habitat conditions.

### 5.3.2 VULNERABILITY ASSESSMENT

**Of all the climate changes considered in this study, increase in temperature is the most important for NTFPs and CWRs, particularly when it occurs during the flowering, fruiting, and seed dispersal and migration times of year.** In the LMB many of the NTFP plants start flowering at the end of the dry season, the hottest time of year—this is when climate change-induced increases in temperature is projected to be most extreme. For several species, notably false cardamom (*Amomum spp)* and paper mulberry (*Broussonetia papyrifera*) the increase in temperature predicted for Mondulkiri during the flowering period could push the species beyond their absolute temperature range, even though modified by forest cover. In other provinces considered, Khammouan, Gia Lai, and Chiang Rai, the temperature changes are less significant and lie within the biological tolerances of the species, although increased temperature may have a significant effect on productivity and fertility and cause decline over time.

The climber, *Dioscorea hispida* would appear to be one of the least vulnerable species, having wide climatic tolerances and well-developed mechanisms for surviving prolonged dry seasons. In contrast, **orchids, e.g., *Dendrobium lindleyi* are considered to be highly vulnerable** especially in Mondulkiri and Khammouan where future increase in temperature and decrease in dry season rainfall will affect its growth and will increase wild fire risk. Increased frequency of storms could also have an impact upon the orchids growing high in the trees. Wild orchids often have complex pollination systems dependent on insects that may also be affected by climate change.

**Changes in rainfall patterns would have a less significant impact on NTFPs and CWRs.** In the hotspot provinces the increases in annual rainfall are well within the normal range for most target species. During the dry season the patterns of rainfall may show a decrease in several provinces, especially in Mondulkiri, and the soil water availability is likely to be reduced. However, unless there are increased periods of prolonged drought (which is possible in Mondulkiri where increased temperatures and reduced rainfall are projected during the dry season), the normal seasonal patterns of dormancy during the dry season and strong growth during the wet season will allow most plants to survive. Some species are even adapted to periods of prolonged drought.

Forest fire is an important ecological feature—both positive for renewal and destructive for loss of individual plants, plant assemblages, and seed banks. **In some areas such as Mondulkiri and Ratanakiri, climate change would enhance the risks of forest fire through more intensive drying and accumulation of litter.** If plants are not given the space and time to recover between incidents of forest fire they will die out. The resin tree species, *Dipterocarpus alatus*, a long-lived species of great importance to local communities but with a low reproductive rate, is vulnerable to forest fire, which can kill seedlings and saplings. Increases in temperature at the crucial flowering period is likely to reduce the reproductive rate further – the species is considered highly vulnerable in most of the hotspot provinces apart from Gia Lai.

**Wetland plant species appear to be the least vulnerable of the NTFP plants considered**. The increased temperature is moderated by the water habitat and may in fact induce growth of the aquatic plants. They are well-adapted to flood, and most are also adapted to periods of drought, and will come back when the flood waters return. **Some of these species, e.g., *Typha orientalis*, are pioneers and may become more invasive under the influence of climate change.** The impact of climate change on wetlands is complex and bound up with other drivers of change. Dams and roads blocking normal flow patterns, for example, are causing major expansion of aggressive exotic invasive species and sedimentation rates. In those areas, the most important climate change effects on the target species may well be indirect impacts which have improved conditions for invasives.

The sedge, *Lepironia articulata* is considered to be moderately vulnerable, largely because it has a fairly restricted habitat requirement which may be subject to grassland fires. With vegetative growth from the rootstock it has the ability to regenerate after such events.

The mangrove, *Sonneratia spp*, is the only species studied here likely to be affected by sea level rise, strong winds, and storm surge. It is considered vulnerable, but if allowed to migrate inland as the seas rise, then it can survive. **If movement inland is constrained by dykes and other developments, as is the case in most coastal areas of the LMB, then mangroves will become highly vulnerable with large areas of forest lost.**

Of the two insect species assessed, the giant honeybee, *Apis dorsata,* is moderately vulnerable. This is because of its life history traits, for example, its great ability to disperse, the special mechanism to tolerate heat, and its genetic variability. The bee possesses a high capacity to adapt to new environmental conditions. Increases in temperature and changing patterns of rainfall may influence the timing of its migrations. If climate change affects the flowering times and quantities in plant species that bees depend on, then this could also have an impact on bee populations. Wild bee pollination is critically important for many fruit crops so any additional stress on bee populations will likely have significant secondary effects on crop production.

Red ants were assessed as having low vulnerability. This species has mechanisms for adapting to changing environmental conditions. Increased maximum temperatures may reduce feeding effectiveness in some areas, for example, in Mondulkiri. Also, red ants nest high up in trees making them more vulnerable to storms and high winds, which is why they are considered more vulnerable in Khammouan.

Earthworms, a keystone ecological species as well as an NTFP, are generally considered to have low vulnerability, apart from in Mondulkiri, where high temperatures and reduced soil water availability may significantly reduce their resilience.

**Wild rice species are highly vulnerable to projected increases in temperature, especially in Mondulkiri**. Wild rice is in a different position to NTFPs because it is not valued by governments or local communities. Like many other important CWRs, they are rarely used by rural people. They may be forgotten by everyone except those interested in rice improvement and genetic research. Their conservation is not given priority by LMB governments. Already, they are under threat from genetic erosion—mixing of genes with cultivated rice—and habitat loss with rapidly increasing pressure of land development for agriculture, urbanization, plantations, or more general forest clearance. Increased temperature from climate change is another significant threat to an already highly threatened group of species.

Table 27 shows the vulnerabilities to non-climate change and to climate change factors of different NTFP and CWR species in hotspot provinces. Mondulkiri Province stands out as being the most extreme in terms of the climate changes and the species vulnerabilities. Chiang Rai stands out as the province where the vulnerability of NTFPs and CWRs to climate change is the least. Gia Lai and Khammouan have an intermediate position. Kien Giang is in a very different situation, and while the threat of sea level rise and storms affects the vulnerability of mangroves, the vulnerabilities of aquatic plants and wild rice species remains low when other drivers of change are not considered.

**In conclusion, the integrity of forest and wetland ecosystems is of critical importance to the natural resilience and adaptive capacity of most of the NTFP and CWR species—without the protection that these provide, their vulnerability would be much greater.**

In all hotspot provinces, the pressures on the natural forests and wetland habitats in which the NTFPs and CWRs thrive is significant and increasing due to such forces as deforestation, illegal logging, encroachment for agriculture, and infrastructure such as roads and hydropower (Table 27). The target species themselves are subject to over harvesting and increased use driven by market demand and higher prices.  Climate change threats are likely to increase the overall vulnerability of many species.

The increases in temperature are the most significant threat.  A species may be pushed beyond its biological tolerances, and raised temperatures at key times of year—flowering, fruiting, and seed dispersal—may affect its reproductive and seed survival rates.

The effects of temperature and rainfall patterns on the interactions between plants, insects, and other invertebrates that make up the ecosystems of which NTFPs are a part are difficult to assess because of their complexity.  The study has tested an ecosystem approach in its vulnerability assessments of protected area clusters reported in the next section.

As climate changes so the mix of species in the forest and aquatic habitat assemblages will shift, favoring some species that can tolerate the new climate patterns better than others.  This is unlikely to be a sudden shift.  Many of the NTFPs have several species or sub-species that are already distributed widely according to different existing conditions, and it is possible that these will "move" to take up new positions as the climate changes.  Effective dispersal mechanisms are therefore an important aspect of species resilience.

**Table 27: Non-Climate change and Climate change vulnerabilities of different NTFP and CWR species in hotspot provinces**

| Province | | | Kien Giang | | Mondul Kiri | | Gia Lai | | Chiang Rai | | Khammouan | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ecozone | | | 3. Delta Low lying acidic area swamp forest | | 6. Low-elevation dry broadleaf forest | | 9. Mid-elevation dry broadleaf forest | | 4. High-elevation moist broadleaf forest - North | | 7. Low-mid ele moist broadleaf forest | |
| **NTFP Category** | **Species** | **Common name** | 2. Delta mangroves and saline water | | 9. Mid-elevation dry broadleaf forest | | | | 12. Upper floodplain wetland, lake (CS to VTE) | | 4. High-elevation moist broadleaf forest - North Indochina | |
| | | | Non-CC Vulnerability | CC vulnerability | Non-CC Vulnerability | CC vulnerability | Non-CC Vulnerability | CC vulnerability | Non-CC Vulnerability | CC vulnerability | Non-CC Vulnerability | CC vulnerability |
| Mushroom | Russula sp | Russula mushroom | | | High | Moderate | High | Moderate | Very high | Moderate | Very high | Moderate |
| Grasses/herbs | Ammomum spp | False Cardamom | | | High | Very high | High | High | High | Moderate | High | Moderate |
| Aquatic plants | Sesbania sesban | Egyptian pea | Very Low | Moderate | | | | | Very Low | Very Low | | |
| | Typha orientalis | Oriental rush | Moderate | Moderate | | | | | | | | |
| | Lepironia articulata | Lepironia Sedge | Moderate | Moderate | | | | | | | | |
| Climbers | Dioscorea hispida | Bitter yam | | | Moderate | Very Low | Moderate | Very Low | Moderate | Very Low | Moderate | Very Low |
| Orchids | Dendrobium lindleyi | Orchid | | | Very high | High | Very high | Moderate | Very high | Moderate | Very high | High |
| Rattans | Calamus crispus | Rattan | | | High | Moderate | Very high | Moderate | Very high | Moderate | Very high | Moderate |
| Shrubs | Broussonetia papyrifera | Paper mulberry | | | Moderate | Very high | Low | Moderate | Moderate | Moderate | Moderate | Moderate |
| Trees | Dipterocarpus alatus | Resin tree | | | High | High | High | Moderate | Very high | High | Very high | High |
| | Sonneratia casseolaris | Mangrove apple | Moderate | Very high | | | | | | | | |
| Insects | Apis dorsata | Giant honeybee | Moderate | Moderate | Moderate | Moderate | High | Moderate | High | Moderate | High | Moderate |
| | Oecophylla smaragdina | Red Ants | | | Moderate | Low | Moderate | Low | Moderate | Low | Moderate | Moderate |
| Invertebrates | | Earthworms | Moderate | Low | Moderate | Moderate | Moderate | Low | Moderate | Low | Moderate | Low |
| **CWRs** | | | | | | | | | | | | |
| **Wild Rice** | O. nivara | | High | Low | High | High | High | Moderate | High | Moderate | High | Moderate |
| | O. officinalis | | High | Low | High | High | High | Moderate | High | Moderate | High | Moderate |
| | O. rufipogon | | High | Low | | | | | High | Moderate | | |
| Landrace rice | O. sativa/prosativa | Floating rice | Very high | Low (An Giang) | | | | | | | | |

| **Vulnerability key** |
|---|
| Very high |
| High |
| Moderate |
| Low |
| Very Low |

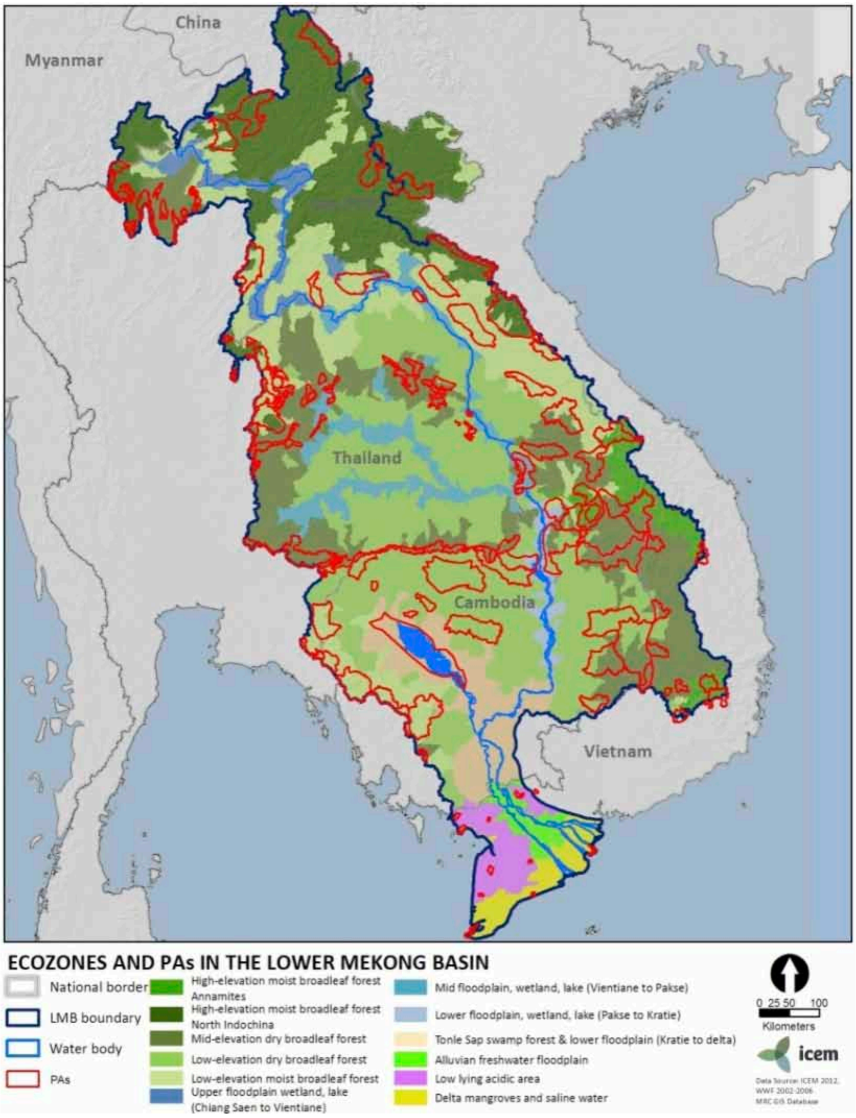
## 5.4 NATURAL SYSTEMS – PROTECTED AREAS

### 5.4.1 BASELINE OVERVIEW

Protected areas are a form of conservation management tenure that aims to protect specific natural features, species, and habitats in their natural state. The four countries have established 115 protected areas in the LMB covering almost 10,000 km² or 16% of the basin and most of its remaining forests and upper watersheds (Figure 5-3 and Table 28)[29].

Thailand has established the most LMB protected areas in number (45, which equates to 39% of the total number across the four countries), but Cambodia and Lao PDR have the most by area (7,608 km² or 78%). Size is important in determining the capacity of a protected area to meet its conservation objectives and its ability to withstand natural and man-made shocks including climate change. Size is an important indicator of resilience.

**Figure 5-3: Protected areas (PAs) and ecozones in the Lower Mekong Basin**




The protected areas in the Vietnamese parts of the basin are small and fragile—much smaller than those in the other riparian countries. They also fall within some of the LMB provinces most threatened by climate change, such as Gia Lai and Kien Giang.

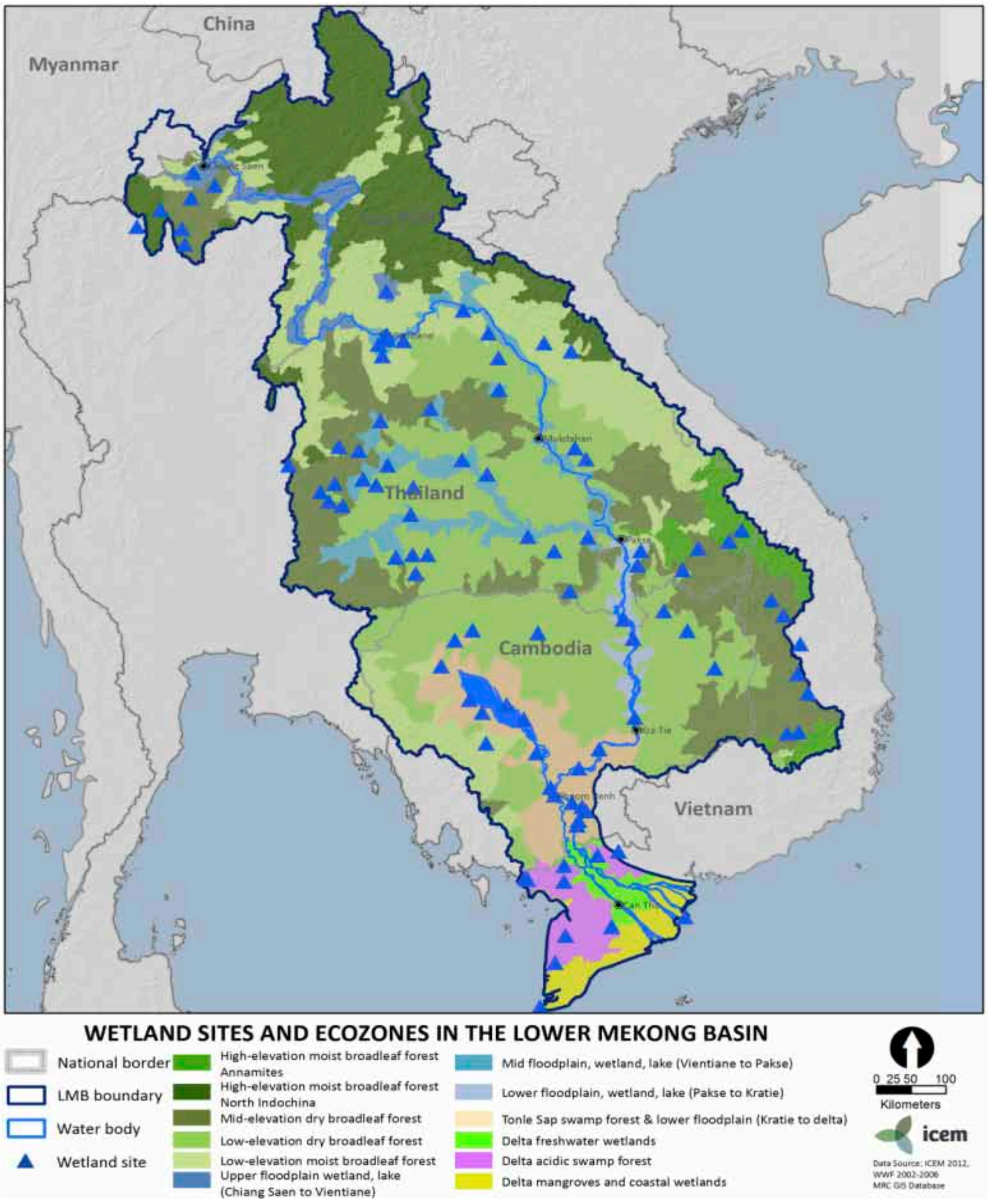
The MRC database includes 94 wetlands of national and international importance for their biodiversity—this study identified another eight that need to be added to the list (Figure 5-4). More than 60% of those wetland areas fall outside the protected area system—with around 50% having some sort of natural resource or conservation management.

[29] In the Lower Mekong countries as a whole, there are about 210,000 km² of protected areas or about 16% of the total land cover.

**Table 28: Protected areas (PAs) in the LMB by country**

| LMB country | No of PAs | Area of PAs (km$^2$) | PAs as % of basin area | Ave size of PAs (km$^2$) | No of important wetlands |
|---|---|---|---|---|---|
| Cambodia | 21 | 3,761 | 6.1 | 179 | 24 |
| Lao PDR | 27 | 3,847 | 6.2 | 143 | 13 |
| Thailand | 45 | 1,824 | 2.9 | 41 | 39 |
| Vietnam | 21 | 383 | 0.6 | 18 | 18 |
| **Total** | **114** | **9,815** | **15.8** | | **94** |

**Figure 5-4: Important wetlands in the Lower Mekong Basin**




Those figures do not provide a full picture of the protected area estate in the LMB. By world standards, the percentage of national area set aside for protected areas is exceptional—at least in Cambodia, Lao PDR and Thailand where it is more than 20% on average (Table 29). In 2003 about half of the remaining forest estate across all four countries was found within protected areas. In the past decade, that figure has significantly increased—likely closer to 70%, especially if quality and biodiversity importance is considered, due to continuing losses in forest cover and quality outside protected areas.

**Table 29: National protected area systems in LMB countries**

| As at 2012 | Cambodia | Lao PDR | Thailand | Vietnam |
|---|---|---|---|---|
| ▪ PAs as a % of national land area | 21 | 21 | 19 | 8 |
| ▪ % of PA system managed at local levels | 5 | 100 | 2 | 94 |
| ▪ Forests in existing and proposed PAs as a % of forest area (2003 figures) | 40 | 39 | 65 | 26 |

Other important trends have been shaping the protected area systems. During the 1990s, the number of protected areas and their total coverage as a % of national land area increased rapidly. In the decade to 2010, Cambodia and Thailand continued to add to their nationally-established protected areas while in Lao PDR and Vietnam the nationally-designated area remained the same. That decade saw significant increases in the number and coverage of locally-established and managed protected areas in Cambodia, Lao PDR, and Thailand. For example, the growth of local protected areas in Cambodia has been remarkable—by 2010 more than 980 were in place (Table 30). Some 60% of those were specially designated areas within existing nationally established protected areas but 40% are in new areas representing a significant increase in the protected area estate, particularly given their critical importance to local livelihoods.

**Table 30: Newly established local protected area in Cambodia (2010)**

| PA type | Number | Area (km$^2$) |
|---|---|---|
| Community forests | 430 | 13,810 |
| Community protected areas | 84 | 930 |
| Fisheries community conservation areas | 469 | 6,837 |

Protected areas now represent the last vestiges of the original plant and animal assemblages of the region. They are the heartland for NTFPs and CWRs—for many the areas of last resort. A very significant issue is that roughly 90% of the LMB's protected areas have communities living within them—and most are experiencing growing populations. More than 25% of LMB protected areas is used for agriculture, 30% for grazing, 30% for fisheries, and 90% for hunting, gathering, and extraction. Also, protected areas in all countries except Thailand are open for major infrastructure development such as hydropower schemes, roads, mining, plantations, and tourism facilities.

All LMB protected areas and linked natural areas of forest and wetlands are of increasing importance as an essential part of healthy productive farming ecosystems—increasing as populations grow and as access to arable land diminishes. There is a direct correlation between population density and the intensity of use of protected areas. Most LMB protected areas tend to fall into the least populated and less accessible locations—although this is changing with increasing migration towards regions of biodiversity wealth. A total of 80% of protected areas are situated in regions of medium to high poverty incidence and there is an increasing dependence of poor on protected areas as a food security safety net.

### 5.4.2 VULNERABILITY ASSESSMENT

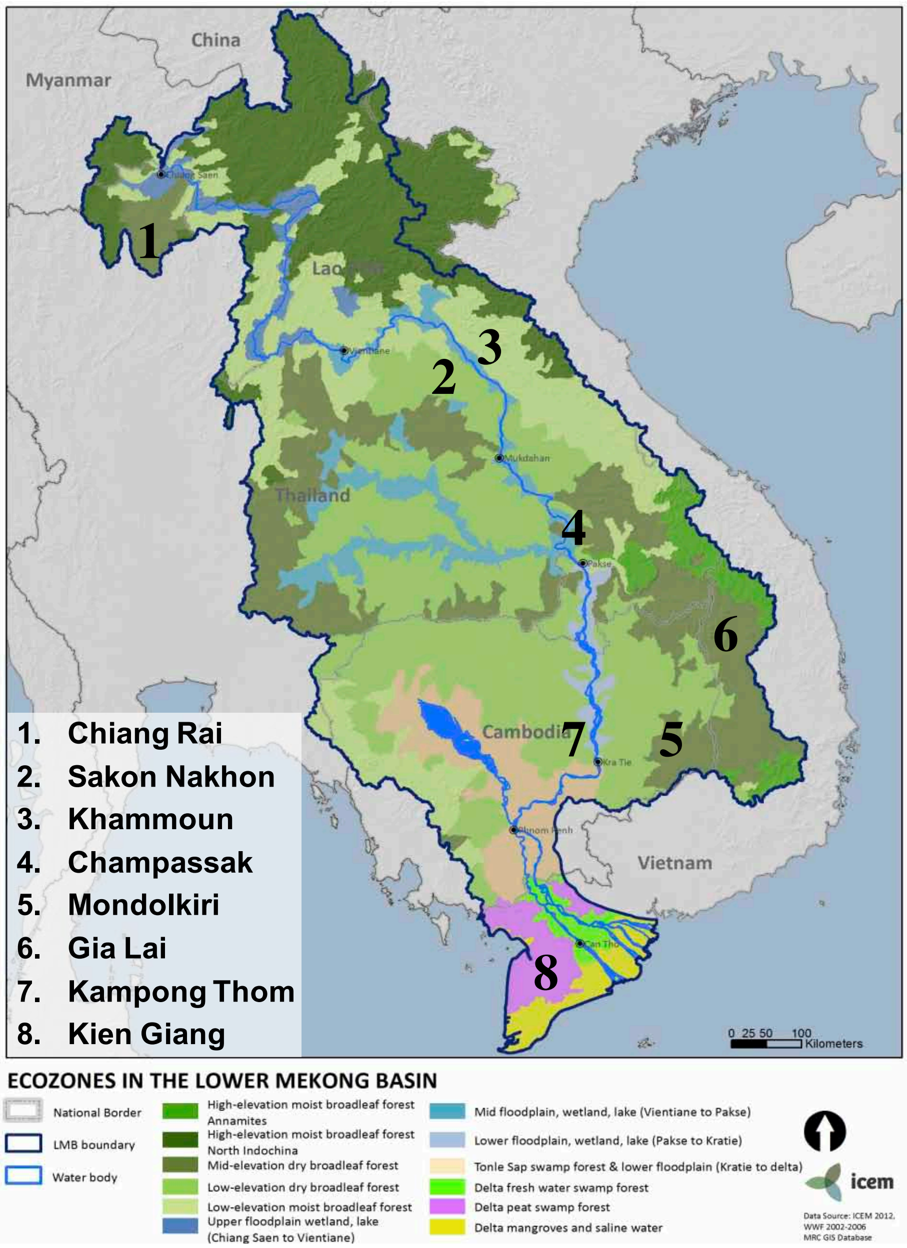
Vulnerability assessments were conducted on eight protected area clusters or individual protected areas within the eight hotspot provinces representing each of the 12 ecozones (Figure 5-5).

The aim was to treat those areas as distinctive ecosystems with a range of characteristics and influences that determine their resilience to climate change. It was important for the team to treat the cluster or individual protected area as a system and to tease out the complex inter-linkages within its special assemblage of plants, animals, and other biophysical characteristics.

The other theme groups focused on individual species—it was the task of the protected area group to draw out the importance of the relationships between individual species and other ecosystem components for climate change resilience.

Inevitably, it was necessary to build on the species assessments already conducted and then to view their influence on ecosystem services. The process and results were summarized on vulnerability assessment matrices for each area. The assessments led to a basin-wide summary of the main impacts and vulnerabilities for protected areas presented here. The full results are reported in the theme volume specific to protected areas.

**Figure 5-5: Protected areas clusters in hotspot provinces in the Lower Mekong Basin**



#### Provisioning Services

Climate change impacts have negative consequences for a number of key provisioning services and assets of protected areas and protected area clusters. *Provisioning services are most vulnerable in buffer zones, in community-use areas, and in the peripheries of protected areas where NTFPs and water sources are most heavily used, where encroachment is most serious, and where exposure to climatic change would be most pronounced.* Services were found to be impacted in a number of ways including:

- **Decline in plant and animal productivity:** Drought in the dry season and increased flooding and soil saturation in the wet season will lead to changes in pollination and flowering, as well as the spread and incidence of disease;
- **Decline and loss of NTFPs**: Reducing habitats and increased reliance and pressure upon NTFPs if agricultural production is impaired; and
- **Decline in water quantity and quality**: Clean water is a key provisional service of protected areas. Increased drought, reduced land cover, and changes in species composition and soil structure may affect the quantity and quality of water entering streams, ponds, trapeangs, and lakes. Similarly, changes in surface water temperature, sedimentation, and flood regimes will impact on water quality and aquatic systems generally.

#### Regulating Services

Climate change impacts were found to affect many protected area regulatory services such as water cleansing, waste breakdown and nutrient recycling, soil erosion, climate (microclimate) control, pest control, and flooding control. Identified vulnerabilities of regulatory services in the protected areas included:

- **Decreased regulation of erosion and sedimentation:** An increased occurrence and decreased interception of sediment in water sources due to more extreme dry and wet conditions exposing and then flushing sediment into waterways.
- **Decreased regulation of flash flooding and landslides:** Projected increased precipitation in the wet season and increased runoff could lead to degradation of habitats, riverbank erosion, bank collapse, and localized landslides.
- **Decreased pest control functions:** Biological control services are expected to decrease in reliability and effectiveness. Various ecological linkages will be disturbed such as insect co-dependence and pest/predator relationships between insects, birds, amphibians, plants, and mammals. Dramatic changes are likely to favor invasive species, displacing native predators, for example, and allowing corresponding native or introduced pests to flourish. In many cases increased ponding and stagnant water is predicted in the wet season—thereby increasing breeding habitat for mosquitoes and other disease vectors. Likewise drought conditions favor pests which have caused considerable damage to crops during drought years.
- **Decreased nutrient recycling functions:** Drier surface litter from higher temperatures will lead to slower decomposition processes and buildup of otherwise recycled products. Losses or decline in certain insect activities may also reduce waste recycling, decomposition processes, and hence, nutrient recycling services.

#### Habitat or Supporting Services

Climate changes would induce ecosystem shifts within the target protected areas. Those shifts would place additional pressure on some already stressed habitats and species. Identified vulnerabilities of habitat or supporting services in protected areas include:

- **Changes in habitat:** Ecosystems are expected to shift or alter under climate change. The shift of certain species to higher elevations or latitudes because of changed temperature and rainfall regimes, for example, could change conditions and symbiotic linkages for other species, as well as lead to the appearance of competing species.

- **Loss of habitat:** Increased risk and incidence of fire is likely to reduce habitat and to disrupt support services. Human settlement and infrastructure will limit the movement of ecosystems and, in some circumstances, prevent ecosystem shifts altogether causing permanent loss of habitats.
- **Reduction/degradation in biodiversity:** In some protected areas, some species are expected to disappear under climate change; others that are better adapted to new rainfall and temperature regimes will replace them. This will change the make-up of ecosystems and create opportunities for more hardy and aggressive native or exotic species such as bamboo and other grassland species that thrive in degraded forests, or exotics in wetlands. Some species may experience a reduction in reproductive cycles and an altered period between flowering and maturing of seeds and propagules.
- **Reduction in species population size:** Higher levels of stress on protected areas from a combination of influences including climate change is expected to lead to an overall loss in diversity and simplification of plant and animal assemblages. The number of species and populations of some remaining species are expected to decline. Migratory species will seek other areas more suitable for breeding and nesting. Reduction in top soil moisture in protected areas of Mondulkiri and Ratanakiri experiencing less rain and increased temperature during the dry season will reduce microflora and fauna suppressing decomposition and nutrient recycling affecting regeneration and plant growth.

#### Cultural Services

Changes to ecosystems are expected to affect tourism, recreation, mental and physical health, and spiritual experiences associated with protected areas, as well as the inspiration for culture, art, and design. Identified vulnerabilities in cultural services in the target protected areas include:

- **Declines in tourism:** Reduced habitat is expected to cause losses in flagship species such as the elephant, tiger, and other cats—and subsequent losses in tourism. Increased intensity and frequency of flooding and storms could destroy tourist facilities and reduce access to tourist sites.
- **Damage to infrastructure:** Flooding, storms, and sea level rise will damage infrastructure and cultural assets in and around the protected areas including roads, culverts/bridges, temples, and tourism facilities.
- **Reduced community well-being and health:** The overall losses in the condition of some protected areas will have an impact on human well-being, especially traditional communities with strong ties to the affected areas. Diseases may spread more easily in hotter and wetter climates un-moderated by diverse natural systems.

### 5.4.3 PROTECTED AREA VULNERABILITY BY ECOZONE

Climate change impacts are projected to vary across ecozones and, consequently, certain ecozones are less vulnerable than others. Drawing from the protected area assessments, major vulnerabilities for each ecozone are summarized below.

**T – Temperature**
**P – Precipitation**
**W – Water availability**
**Sa – Salinity**
**Sl – Sea level**
**D – Drought**
**F – Flooding**
**S – Storm**

Very High
High
Medium
Low
Very Low

**Upper floodplain wetland, lake** T P W D F S

Representative of this ecozone is *Nong Bong Kai – Non-Hunting Area in Chiang Rai*, Thailand. It has very high vulnerability to changes in (i) temperature—maximum temperature during the dry season is projected to increase up to 42.5°C; and (ii) flooding due to greater intensity of rainfall during the wet season leading to flooding and flash flooding. Consequently:

- Important aquatic species that are sensitive to the high projected temperature increases will experience declining populations, particularly in already degraded habitats;
- Sedimentation and the degradation of water quality due to higher temperatures will affect fish habitat (e.g., loss population and/or changes to migration patterns), macro-invertebrate species, and aquatic plant communities;
- The invasion of exotic species, particularly aquatic weeds such as cogon grass, will become a threat to wetland ecosystems under warmer conditions;
- Increased flooding intensity, frequency, duration, and depth will destroy subsistence crops, livestock and agricultural areas, and wetland wild products;
- Flooding is associated with increased crop diseases, insects, and rodents; and
- Flooding will damage infrastructure and cultural assets in and around the protected areas—including roads, bridges, houses, resorts, and tourism facilities.

**Mid and low-elevation dry broadleaf forest** T P W D F S

Representative of this ecozone is the *Mondulkiri protected area cluster in Cambodia*. The ecosystem is projected to be exposed to: (i) an increase of 3°C to 4°C in maximum temperature; (ii) a decrease in rainfall and water availability during the dry season; (iii) an increase in the frequency and duration of drought; and (iv) increasing intensity of rainfall and flash flooding. The baseline condition of this area is very dry and ecosystems are degraded and stressed by a range of influences. The main climate change threats and vulnerabilities are:

- Declining water availability due to hotter and dryer conditions during the dry season reducing crop productivity;
- Reduced habitat for important commercially-exploited NTFP species, such as resin trees and cardamom due to high temperature increases throughout the year;
- Earlier and longer drying of seasonal trapeang ponds leading to severe water shortages for dependent biota;
- Incursion by invasive species causing biodiversity losses and simplification, for example in the case of climax bamboo grasslands in degraded forest areas;
- Increasing sediment and nutrient loads in aquatic systems, due to drier soils and early and more intense onset of the monsoon following more extreme dry seasons, will affect populations of some fish species and encourage algal growth; and

- Increased fire risk and subsequent destruction of habitats and biodiversity.

**High-elevation moist broadleaf forest** T P W D F S

Representative of this ecozone is *Nakai – Nam Theun NBCA in Khammouan, Lao PDR*. The ecosystem is most vulnerable to flooding, particularly flash floods. Significant rainfall during the wet season will be associated with more frequent flash floods and landslides. The main vulnerabilities of this ecosystem associated with flooding are:

- Seasonal destruction of subsistence crops and livestock and agricultural areas;
- Reduced access to forest products, e.g., NTFP gathering;
- Direct destruction of habitat and the spread of invasive exotics when combined with other disturbances; and
- Natural system provisional services becoming more important during and after extreme flooding, leading to greater exploitation of forest products if agricultural lands are destroyed and access to markets is reduced.

**Low-mid elevation moist broadleaf forest** T P W D F S

Representative of this ecozone is *Hin Namno, Phoun Hin Poun, Corridor Nakai – Nam Theun, Phou Hin Poun in Khammouan, Lao PDR and Chu Prong in Gia Lai, Vietnam*. This ecosystem is most vulnerable to flooding with similar impacts to those identified for high-elevation moist broadleaf forest. Temperature changes are also projected to have high impacts on this ecozone, for example:

- Higher temperatures during the dry season increasing evapotranspiration and reducing water availability for agriculture and domestic uses;
- Higher temperatures during the dry season creating drier soil surface layers and leading to increases in erosion and soil loss, particularly in already degraded areas;
- Increase of 5°C in the wet season leading to higher surface water temperature that would affect aquatic plant growth with implications for fish health and nursery areas;
- Temperature increases could lead to habitat shifts, in terms of both location and elevation, particularly in over-logged areas at the edge of the Bolaven Plateau and the base of the Dividing Hills; and
- Higher temperatures affect migration of waterbirds and the movement of larger species such as tigers, guars, and large cats within habitat clusters, i.e., through the existing wildlife corridor.

**Delta mangroves and saline water and delta low-lying acidic area swamp forest**
T P W Sa Sl D F S

Representative of these ecozones is the *Kien Giang protected area cluster, Vietnam*. This ecosystem has very high vulnerability due to a 2°C to 4°C increase in temperature and increases in rainfall, flooding, and storms as well as sea level rise. The specific vulnerabilities of the ecosystem under climate change are:

- Mangrove leaves are sensitive to temperature and their photosynthetic capacity reduces, falling to zero at leaf temperatures of 38°C to 40°C. Their optimum leaf temperature for photosynthesis is 28°C to 32°C. Increases in temperature may adversely affect flowering and change the reproductive cycle and duration between flowering and the fall of ripe seeds

(Kathiresan 2012). Habitat losses are projected affecting many coastal and marine species and changing migration patterns of important bird species;

- Sea level rise will exacerbate flooding by restricting drainage; increasing erosion of coastal areas and riverbanks; causing habitat loss, particularly mangroves; raising soil salinity levels; and reducing the viability of current areas of human settlement, causing many households to migrate inward to higher ground, which will affect the management regime of *U Minh Thuong* and other important wetlands;
- Heavier rainfall will reduce the capacity of local canals to drain, causing flooding and inundation in the surrounding floodplain, which will subsequently disrupt and destroy crops;
- Early onset of the monsoon following a drier dry period is expected to increase erosion, sedimentation, and nutrient deposition in wetlands and water sources; and
- Projected high temperatures will reduce water availability for agriculture and domestic uses.

The vulnerability assessments of protected area clusters found that climate change-induced ecosystem shifts in LMB protected areas will result from: i) geographic shifts in species ranges due to shifts in regular climate; ii) substantial range losses for individual species; iii) seasonal shifts in life cycle events such as advances in flowering due to changes in temperature; (iv) changes in animal migration patterns; (v) changes in fish migration due to changes in the onset of the flood season; vi) decreased body size due to higher temperatures; vii) community composition changes, for example species adapted to higher temperatures will become more predominant; and viii) genetic changes such as tolerance shifts. Those species and genetic changes will lead to fundamental changes to the ecological make-up of protected areas in the LMB.

## 5.5 CAPTURE FISHERIES

**Fisheries & aquaculture are vitally important for food and for the livelihoods of people of the Mekong Region.** The vast majority of rural families are involved in fishing at some time of the year and small-scale capture fisheries remain a "livelihood of last resort" for many rural families. In recent decades aquaculture has boomed providing livelihoods to hundreds of thousands of households. **Climate change will challenge these traditional and contemporary ways of life at fundamental levels.**

### 5.5.1 CAPTURE FISHERIES BASELINE OVERVIEW

Capture fisheries of the LMB are crucial for the food security of the region**.** They are thought to contribute about 1.9 MT/yr, accounting for over half of the total inland fisheries yield of 2.6 MT/yr with a market value of US$3.9-7 billion. **This represents about 2% of the world's total marine & freshwater capture fishery.**[30]

**The biodiversity of the Mekong capture fishery is extraordinary**. The number of fish[31] species in the LMB is estimated to be 500 to 1,200,[32] although a high degree of within-species diversity also exists. There are thought to be several hundred species that science has yet to discover, particularly in the upper catchment areas, and some of the well-known lowland species may in fact comprise assemblages of several species.

[30] Despite a series of recent revisions, capture fisheries are still probably under reported in statistics. For example, some countries do not include fish production from rice fields and swamps in their inland fisheries statistics.
[31] The use of the term 'fish' is used in a broad sense and refers to any edible aquatic animal, including mollusks, crustaceans, amphibians, reptiles, and insects.
[32] Some reports suggest that the number of fish species that have been found in the LMB may exceed 2,000.

**Almost all fish species[33] caught from the fishery have a commercial value.** Even poisonous fish species such as *Tetronodon* spp can be prepared for consumption and have a market value. The Siamese mud carp, *Henicorhynchus siamensis,* can be singled out due to its huge importance for fish paste production in the LMB countries.

**The biodiversity and productivity of the Mekong capture fishery is linked inextricably to the strength of the annual flood pulse and the connectivity of the diverse range of natural habitats, (e.g., streams, floodplains, and permanent wetlands), as well as some artificial habitats (e.g., rice fields and reservoirs).** The flood pulse inundates terrestrial food sources and liberates nutrients from sediment, supporting high primary productivity and in turn the food chains that fish depend upon. Many fish and other aquatic species migrate between feeding, spawning, and resting habitats.

Catches tend to show seasonal trends related to water level, flow, and fish migration. The highest catches are made at the beginning of the wet season (June–July) when many fish are migrating to breeding grounds and at the end of the wet season (November–December) when fish are migrating off flooded areas and moving towards dry-season refuges. At present, the fishery remains in a very productive state and there is no evidence of declines in overall productivity.[34] **However, there are clearly serious declines in the numbers and sizes of certain species**, including most of the famous Mekong giant fish species, e.g., *Catlocarpio siamensis,* suggesting that these stocks are being over-fished.

The Mekong fishery is dominated by the use of small-scale gears operated by individuals. At least 80 categories of gear have been identified in Cambodia alone. Women are actively engaged in fisheries-related activities throughout the LMB, particularly on the post-harvest side. Children are also involved in fishing, mainly for homestead food security. In addition to the major fish groups, there are a large number of other aquatic animals that are important for consumption and income generation, particularly amongst the poorer people of the LMB. These include crustaceans, amphibians, mollusks, and edible aquatic insects. Processed fish products such as fish paste are important during low fish production periods. **Despite the seasonal abundance of fish, many of these households remain desperately poor and have few other livelihood opportunities. A decline in the Mekong capture fishery would be catastrophic for them.**

The fishes of the Mekong can be grouped broadly according to their ecology and migration behavior. The fishes of the small streams and tributaries in the **upland** areas of the Mekong basin are often overlooked by fisheries managers, as their contribution to total fisheries productivity (but not biodiversity) is modest. Although modest in size, these small upland fisheries are important to upland communities, increasingly as other hunting options become less viable. As a result, an increasing number of upland households now rely on fish products from small water bodies and streams in the uplands. Foraging for these products is often done under a wider NTFP mandate. The fish, which inhabit the cool clear waters of upland forests, look particularly vulnerable to a wide range of pressures, including climate change.

---

33 Commercially important species/genera include: *Channa sp, Puntius sp, Leptobarbus hoevenii, Pangasias sp, Wallago attu, Kryptopterus aponogon, Notopterus sp, Anabas testidudineus, Oxyeloetris marmorata, Mystus sp, Clarias sp, Trichogaster sp, Clupea thibaudeaui, Thynnichthus thinnoides, Labeo sp, Cirrhinis microlepis, Hilsa sp, Osteochilus melanopleura,* and *Sciaenidae sp.*

34 The Cambodian Fisheries Administration's monitoring of the Dai fishery on the Tonle Sap, (now in its 8th year), is a useful proxy for the general health of the Mekong system. The study shows a fairly strong correlation between water levels, flood durations, and fish yields. The available data do not support the view that there is a present decline in the total production from the fishery.

**The "Black Fish"** group comprises those species with limited lateral migrations from the river onto the floodplains and no longitudinal migrations upstream or downstream. They do not leave the floodplains and wetlands, and spend the dry season in pools in the rivers or floodplains. This group includes the Channidae (snakeheads), Clariidae and Bagridae (catfishes) and Anabantids (including the climbing perch). Most Black fish species are able to survive harsh water quality conditions (such as low DO, low pH, high turbidity, and high ammonia), and their limited migratory habits may make them less vulnerable to wetlands and riverine fragmentation. As a result, this group of fish species may be less affected by climate change than the other groups.

**The "White Fish"** group account for around 87% of Mekong fish species and 50% of the total catch. Many of them undertake long distance migrations,[35] in particular between lower floodplains and the Mekong mainstream and tributaries. The White fish group includes many cyprinids (e.g., *Henicorhynchus* spp. and *Cirrhinu*s spp.) and also most Pangasiidae catfishes. White fish species require higher water quality conditions in terms of DO and alkalinity and are more vulnerable to increased temperatures, especially at maturation and fry stages. The effects of climate change on some of these species may therefore be severe. **The decline of migratory white fish would have a great effect on local communities who have relied on these seasonal resources for generations.**

**The "Grey fish"** group is an intermediate category that does not spend the dry season in floodplain pools nor undertake long distance migrations. When the floods recede they tend to leave the floodplain and spend the dry season in local tributaries. This group includes some of the *Mystus* catfishes. The effect of climate change on this group of fish is regarded as intermediate.

**Estuarine fish** are found in the lower reaches of the Mekong system and include many species tolerant of a wide range of salinities due to the great variation in annual freshwater flows, e.g., sea bass (*Lates calcarifer*). These species will be vulnerable to certain aspects of climate change, e.g., temperature increases in shallow coastal areas, but less vulnerable to others, such as sea level rise. Estuarine fisheries support many coastal communities in the Mekong Delta and their decline through climate change would affect the livelihoods of many people, most of whom have few alternative livelihood options.

In certain parts of the LMB, **exotic fish species** such as common carp (*Cyprinus carpio*) and rohu (*Labeo rohita*) have become established and now form feral populations. In total, about 17 exotic species are known to have established wild populations in the LMB, and this is of growing concern.[36] Many of these feral fish populations have gained a foothold in natural habitats through escapes from fish farms. Some of these species may benefit from the projected climate change conditions, which will increase pressure on indigenous fish species.

[35] For example *Pangasius krempfi* migrates many hundreds of kilometers from the South China Sea to Northern Laos where it spawns.

[36] The Cambodian Fisheries Administration has prohibited aquaculture of one exotic species, the red-bellied pacu, *Piaractus brachypomus*, but without enforcement and similar action in other countries, this ban will likely not be effective.

### 5.5.2 CAPTURE FISHERIES VULNERABILITY

**To an extent, capture fisheries in the LMB is buffered against climate change by the exceptionally large aquatic ecosystem biodiversity. As a result, some species will likely benefit from the changing conditions, possibly maintaining the overall fisheries productivity, while other less adaptive species will decline. This is likely to lead to an overall loss in biodiversity.**[37]

Very little is known about the tolerances to water quality conditions of most Mekong fish species. However, species within the same groups do have similar water quality requirements. When examined in this way, **the threats from climate change look daunting. Increased temperatures, changes in rainfall and river flows, sea level rise, and increasing storm intensity will all affect fish biodiversity and productivity.** Some of these threats, such as reduced rainfall and higher temperatures during some months in the dry season, will create extremely harsh conditions that some fish species cannot tolerate.

Changes to **habitat temperature** will influence metabolism, growth rate, production, reproduction (seasonality and efficacy), recruitment, and susceptibility to toxins and diseases, affecting the natural ranges of some species and resulting in changes in biodiversity in some areas. Disease ranges may also be extended through increased temperatures.

Increased temperatures may allow some robust invasive species to compete more effectively with indigenous species, increasing their range and impacts. Lower DO levels in warm water as temperatures rise will tend to favor black fish over white fish, resulting in a shift in the balance of species composition and reduction in some fish populations. Increased phytoplankton populations will stimulate the productivity of some fisheries but harmful algal blooms could also result, affecting fish survival or production.

Changes in **rainfall** patterns are likely to affect fisheries in a number of ways. Erratic rainfall could affect the flood pulse cycle of the Mekong River, affecting the hydrology of the Tonle Sap Great Lake and fish migrations, reproductive success, and the fish production that results. Prolonged dry periods could affect the survival of fish through the dry season, particularly in upper Mekong floodplain areas, already under pressure from hydropower development, over-fishing, and agriculture intensification.

The Mekong Climate Study projection that is most significant for capture fisheries is that the wet season will be longer and wetter. **This may favor many of the aquatic species in the LMB.**[38] However, this may be an overly simplistic view. For example, a strong freshwater pulse during a peak temperature period (March-April) could affect the reproductive success of some species. In addition, the permanent flooding of some areas that were previously seasonally-inundated habitats, could affect fish biodiversity and production in subtle ways.

Increased erosion in catchments will affect river floodplain water quality reducing fish reproductive success and productivity. Increased runoff from inland areas could also result in the flooding of coastal lowlands, altering salinities and increasing fluvial deposition. Reduced rainfall during the dry seasons will reduce the capacity of upland streams to hold water for maintaining upland fish stocks. Flash flooding through increased rainfall during the wet season may affect habitats and the

---

[37] Assessing the vulnerability to climate change 'signal' in the Mekong fisheries is challenged by the 'noise' from other factors. The largest single threat to the diversity and productivity of the Mekong fishery is without doubt the alteration of river morphology caused by physical barriers such as dams.

[38] Research in Cambodia has shown a fairly strong correlation between water levels, flood durations, and fish yields.

reproductive success of some species. **Only those species able to handle these new extremes will proliferate.**

**Increased sea levels** are likely to affect coastal fisheries through the migration of coastal mangrove areas northwards or through serious reduction in habitat if that migration is constrained. **Increased storm intensity and frequency** will result in saline inundation of freshwater areas farther inland, resulting in periodic fish kills.

Vulnerability assessments in the six hotspot provinces show that upland fish species and migratory white fish will be most vulnerable to climate change in Chiang Rai, Gia Lai, and Mondulkiri. Migratory white fish will be most vulnerable in Khammouan. In Kien Giang, estuarine species will be most vulnerable and one invasive rice pest species (the golden apple snail) will become more widely distributed. Black fish species do not look particularly susceptible in any of the hotspot provinces.

**The vulnerability assessments confirm the hypotheses:**

- Upland fish will be the most vulnerable to climate change;
- Migratory white fish will be vulnerable to climate change;
- Black fish will be more "climate-proof" than other fish types; and
- Invasive species will become more prevalent through climate change.

## 5.6 AQUACULTURE

### 5.6.1 AQUACULTURE BASELINE OVERVIEW

**Aquaculture has been a long-established activity in parts of the LMB, particularly on the Tonle Sap Great Lake and the Mekong Delta. However, over the past 30 years, the Mekong's aquaculture sector has boomed. For the region, the latest annual production estimates of around 1.9 MT suggest that nearly half of the region's fish are from cultured systems.** Although much of this production is by the private sector and destined for export, as the Mekong countries become wealthier, the local and regional demand for diverse, high quality, and "new" fish products is expected to increase. The overall demand for fish from the Mekong aquaculture systems is therefore expected to increase. **Participation in aquaculture in the Mekong mirrors that of capture fisheries in that it is predominantly small-scale operation.** Even the more intensive systems tend to be done by groups of individual households rather than large companies.

Semi-intensive and extensive aquaculture systems are common throughout the region and are particularly important in supporting small-scale farming households. These systems often include a significant proportion of wild fish in the harvests. Traditionally, many aquaculture systems depended on capture fisheries for wild-caught juveniles for culture and low-value fish for feed. Semi-intensive and extensive aquaculture systems often include a significant proportion of wild fish in the harvests. Therefore, there has always been a close integration of fisheries and aquaculture in the Mekong. To some extent, the development of hatcheries and the availability of commercial fish feeds throughout the region have reduced this dependency on wild resources. Effective networks of fish seed producers and distributors have emerged in Thailand and Vietnam and are emerging in Cambodia and Lao PDR. Strong promotion by the region's governments is providing effective technical support for this development.

**A wide range of indigenous and exotic aquatic species is cultured in the LMB**. The most important species for aquaculture is the *Pangasius* catfish (*Pangasius pangasius*), grown mainly in the delta. Other important species include snakeheads (*Channa micropeltes*), tilapia (*Oreochromis niloticus*), giant freshwater prawn (*Macrobrachium rosenbergii*), and the tiger shrimp (*Penaeus monodon*). Additional important indigenous species include*: Pangasius sp, Barbodes gonionotus, Clarias sp, Channa sp, Anabas testudineus, Trichogaster pectoralis, Oxyeleotris marmorata, Macrobrachium rosenbergii,* and *Osphrenemus goramy*. A large number of exotic species are also cultured, often in polyculture with indigenous fish, and these include the Chinese carps, Indian carps, *Oreochromis spp, and Colossoma sp.*

The virtual disappearance of some popular and high-value fish species from many of the capture fisheries, (e.g., *Oxyeleotris marmorata*) and the growing market acceptance of lower value exotic fish species, such as tilapia, are **creating new market opportunities for aquaculture products.** There is also a growing demand for the restocking of depleted fisheries[39] with fish from hatcheries. **The aquaculture sector therefore looks set for continued growth, generating considerable wealth and creating new livelihood opportunities for rural people.**

**The flip side of aquaculture is the effect on the region's capture fisheries and their environments**. Large areas of mangrove and/or rice fields, supporting capture fisheries, have now been converted to shrimp farms with obvious negative effects on the surrounding coastal fisheries. Large freshwater wetland areas considered suitable for the expansion of inland aquaculture have also been targeted by commercial investors.

### 5.6.2 AQUACULTURE VULNERABILITY

**To an extent, aquaculture in the LMB is also buffered against climate change by the wide range of species and production systems. However, production in the intensive aquaculture systems has probably peaked and current production levels may not be maintained under the projected climate change scenarios. Most systems are already managed close to the limit of their sustainability. Semi-intensive and extensive systems may be more robust but are likely to be affected by the extremes of droughts and floods that their operators may struggle to manage effectively.**

Climate change stress on the aquaculture systems include increased temperatures, changes in rainfall patterns and water availability, increased storm intensity and frequency, and sea level rise. As with the capture fishery, some of these variables, such as reduced rainfall in the dry season and higher temperatures will work in tandem, creating additional pressure on aquaculture systems.

Increased **temperatures** resulting from climate change are likely to affect aquaculture in the LMB in negative ways. Some aquaculture species may be unable to tolerate elevated temperatures, e.g., *Penaeus monodon,* or have difficulties breeding at higher temperatures (such as *Cyprinus carpio*). Higher temperatures will result in increased decomposition rates and eutrophication, leading to increased fouling of structures such as nets, and reduced DO levels, which may incur additional costs associated with aeration. **While aquaculture may become possible or more viable in higher elevation areas, this will not come close to compensating for the losses from lowland areas.**

[39] For example, *Macrobrachium rosenbergii* juveniles were released in floodplains in Cambodia by the Fisheries Administration.

Changes in **rainfall** patterns are likely to affect aquaculture as it becomes more difficult to prevent the loss of stock through flash flooding. Longer dry seasons may affect freshwater availability, especially if there is increased competition from other users, thereby constraining fish production.

**Storm intensity and frequency** could affect coastal and reservoir aquaculture infrastructure and inland aquaculture farm flood security. Changes in stream and river water quality caused by increased erosion through storms and increased rainfall will require substantial additional investment to manage. Increased **sea levels** are likely to reduce the area available for aquaculture. Increased inland flooding may result from more extensive inland reach of tides and restrictions of freshwater runoff to the sea. In this scenario, freshwater and brackish water species most tolerant of salinity, such as *Oreochromis* will be favored. Freshwater aquaculture farms may have to move inland as water levels rise, while new areas for brackish water aquaculture may emerge.

**The vulnerability assessments confirm the hypothesis that aquaculture will be more vulnerable to climate change scenarios than capture fisheries.**

**The vulnerability analysis in five hotspot provinces suggests that intensive aquaculture systems would be negatively affected in all hotspots**, with one exception—Mondulkiri**.** This would be particularly damaging for the delta region that has become economically dependent on aquaculture in recent years. Intensive systems will have a much higher water quality and quantity demand than more extensive systems to keep problems at bay such as pollution or diseases (becoming more of a problem with increased temperatures).

For example in **Kien Giang** the pond production of freshwater prawns looks particularly susceptible to increased temperatures, increased precipitation, decreased water availability, and drought. However, these look manageable and local people should be able to cope with the changes. **In the coastal areas, the pond culture of shrimp will be seriously compromised by climate change. These systems are already under threat from environmental factors and aggressive management practices and climate change may well push them over the edge**.

**In some middle and higher elevation areas, aquaculture may benefit from the warmer temperatures and increased water availability anticipated through climate change.** High indigenous and exotic fish diversity will allow for farmers to select species that are most suited to the changing temperatures. However, extra money will have to be spent on protecting some farms from the anticipated flooding resulting from increased and erratic rainfall.

**The hypothesis that intensive aquaculture will be more vulnerable than semi-intensive or extensive systems does not appear to hold completely true, as the assessments also highlighted the vulnerability of semi-intensive systems in Chiang Rai, Kien Giang, and Mondulkiri and the vulnerability of extensive systems in Chiang Rai, Khammouan, and Mondulkiri**. The conclusion that semi-intensive and extensive systems will be affected to a similar extent as intensive systems is based on the idea that while all systems are all vulnerable to flooding (in particular flash flooding) and drought or water shortages during the dry season, the larger and more intensive systems, although at greater risk of economic loss, have greater capacity for management and adaptability.

Many of the poorest people in the region rely heavily on fish production from aquaculture as a regular source of protein. In many areas aquaculture fish are now cheap, relative to fish from the capture fishery. **Increased costs of farmed fish resulting from climate change adaptation costs could therefore have a serious effect on the quality of poorer people's diets. No other obvious animal protein alternatives exist.**

# 5.7 SOCIO-ECONOMICS (HEALTH AND INFRASTRUCTURE)

## 5.7.1 LIVELIHOOD ZONES OVERVIEW

This section provides a description of the five livelihood zones first introduced in Section 3.1.2.2. It informs the later discussion of climate change vulnerability in each zone.[40]

### 5.7.1.1 Forested uplands

Upland areas in the LMB typically comprise sloping hills or mountains adjacent to highly productive valleys. This study distinguishes between *Forested uplands* and *Intensively-used uplands*. *Forested uplands* exhibit low population density (<50 persons/km$^2$) and substantial remaining forest cover (Johnston et al. 2009). Communities in this zone predominately pursue subsistence-based livelihoods. *Intensively-used uplands* consist of higher density areas (>50 persons/km$^2$) with substantial tracts of land cleared for commercial agriculture. The boundaries between the two areas are shifting over time and the distinction does not precisely delineate the two zones at the regional level.

*Forested uplands* are characterized by limited land suitable for paddy rice (due to steep slopes) and a relatively high proportion of the population consisting of poor ethnic minorities. These areas are concentrated in the north and southeast of Lao PDR, the east of Cambodia, and in parts of the Vietnamese Central Highlands. Communities in this zone pursue subsistence-based shifting cultivation and livestock rearing, with limited commercial cropping. The poverty rate is the highest across livelihood zones in the LMB. Lack of access to public infrastructure, including health centers, roads and electricity, and markets is a common problem in these areas. Very poor health conditions and low literacy are also common features. NTFPs are important sources of income and food, particularly in times of food insecurity. A major characteristic of livelihood systems in the LMB is the high diversity of activities that households employ; this trait is most evident in *Forested uplands* and, in many cases, reflects the more marginal status of household food security.

Although these areas are labeled *Forested uplands*, their natural state is degraded and under threat. Deforestation and the encroachment of plantation or commercial cropping is changing the landscape and, more importantly, reducing the access of rural communities to ecosystem services. These changes, as well as the shortening of fallow periods for shifting cultivation (due to increased demand for food), are major drivers of land degradation. Key crops in this zone include: upland rice, other cereals, vegetables, and other subsistence-based crops. Although commercial fishing is limited across most of this zone, many households fish in upland streams on a subsistence basis.

### 5.7.1.2 Intensively-used uplands

*Intensively-used uplands* encompass high elevation more densely populated areas. This zone makes up the majority of the Vietnamese Central Highlands region, parts of northern Thailand and some small areas in Cambodia and Lao PDR. Most of this zone falls within Thailand and Vietnam. Farming in these areas focuses on commercial cropping of coffee, irrigated rice (predominantly in valleys), pepper, rubber, and other crops. Given the high value and commercial orientation of these crops, the average level of income and the quality of infrastructure are generally higher than in *Forested uplands*. This is also broadly the case across a range of important variables, such as access to markets, as well as access to health and education facilities. Yet, there remain highly vulnerable groups in certain areas of this zone.

---

[40] Profiles of the social and economic characteristics of the five hotspot provinces are annexed to the Social and Economic Assessment theme volume.

The intensive nature of farming, often on unsuitable land, is driving widespread erosion and reducing soil fertility; with the consequent risk of flooding and landslides on sloping land. Although farmers can earn high profits from commercial crops, the intensive nature of their farming and the high cost of inputs leave them highly exposed in the event of crop failure or unfavorable price shifts in the market.

Figure 3-7 (Section 3.1.2.2) shows the many borders between intensively-used uplands and forested uplands in the basin. This border is shifting as agricultural expansion and logging move into new forest areas. These borders are the sites of the "system leaps" referred to earlier in this report relating to the agricultural transformation going on in the basin. These leaps move affected communities into a completely different system wherein the productivity and availability of natural systems and the livelihoods they support is greatly diminished.

#### 5.7.1.3 Lowland plains and plateaus

This zone covers the largest proportion of the basin. Aside from northeast Cambodia, these areas are extensively cleared of forest cover. Agriculture is primarily rainfed and the most significant crop is rice. Other important crops are maize, sugarcane, cassava, and soya bean. Large-scale plantations of industrial crops such as rubber, eucalyptus trees, and cassava are becoming more common in the region; many of these plantations arise from foreign direct investment.

Poverty is significant in *Lowland plains and plateaus*, but varies greatly between the intensively irrigated areas of northeast Thailand and the plains of Mondulkiri in Cambodia. By and large these areas have better infrastructure and access to services than more remote *Forested uplands* areas, but less than the *Floodplain* zone. Similarly, population density outside of urban areas is also higher than *Forested uplands* (except for north-eastern areas of Cambodia) and lower than the *Floodplain* zone. The greater distance to commercial centers (compared to the *Floodplain* zone) means that wage income is less important and subsistence systems remain significant in the many remote regions of the *Lowland plains and plateaus* zone.

Communities in the zone often live in riparian areas. This means that they are more exposed to flooding than their counterparts in upland areas; it also means that fishing takes greater prominence in livelihood strategies, including commercial fishing amongst a small proportion of households. The dominant form of fishing is capture fisheries. Irrigation in this zone is limited in Cambodia, extensive in Thailand, and moderate but growing in Lao PDR. Except for areas around major rivers, the quality of soil in *Lowland plains and plateaus* is often poor and therefore generates low agricultural yields for many crops.

#### 5.7.1.4 Floodplain

The *Floodplain* zone consists of areas immediately adjacent to the Tonle Sap, and areas to the east and south of the Tonle Sap where the hydrological interaction between the lake and the Mekong River causes major annual floods of riparian areas of the Mekong mainstream and some major tributaries. In these areas, flooding is a seasonal event that is a critical factor in the high productivity of agriculture and fisheries. This productivity is reflected in the high population density of the *Floodplain* zone and the relatively high level of income and food security. This higher population density also means that households have better access to markets, health centers, education, and infrastructure. The downside of these higher concentrations is that the ecosystem, particularly the Tonle Sap, are degrading from such activities as forest clearing and agricultural encroachment.

Subsistence fishing is a critical source of food security, even if fishing is not a household's principal activity. Commercial fishing (including aquaculture) as a primary or secondary activity is common amongst many households. Irrigation is relatively underdeveloped around the Tonle Sap, where wet rice and recession rice are dominant. Rice, as with most other areas within the LMB, is the dominant crop.

#### 5.7.1.5 Delta

The *Delta* zone consists of three ecozones within the Mekong Delta. These areas are the most intensively farmed in the region and rice yields are generally much higher as a result. More than half of Vietnam's rice production originates in the delta and this area has been almost completely converted from marshes/wetlands to a system of dykes and man-made waterways supporting paddy rice. The sustainability of landuse in these areas is under question—declining soil fertility, water pollution, and other environmental factors threaten future production. Poverty and food insecurity rates are low by regional standards and population density and access to infrastructure and markets are relatively high. Despite this relative wealth, the intensive, high-input nature of farming means that households are exposed to adverse shocks that affect income. Instead of there being a large number of households in a state of poverty, a large number are at risk of being forced below the poverty line when they lose revenue because of extreme weather events or instances of pests and diseases.

Coastal delta regions are influenced by ocean hydrology, and livelihoods are heavily dependent on offshore fisheries, saline and brackish water aquaculture, and use of estuarine resources (i.e., clams and shrimp). Wet rice in these areas is vulnerable to saline intrusion and rice production is more marginal and involves greater risk than in other parts of the basin. Mangroves are an important source of NTFPs, particularly for firewood but are reducing in area and quality through aquaculture and other forms of development.



### 5.7.2 HEALTH AND RURAL INFRASTRUCTURE OVERVIEW

**Health and infrastructure conditions are closely related**. Indicators for health and infrastructure tend to be highly correlated as poor health and poor infrastructure are both closely linked to more fundamental causal factors such as geographical location. Health outcomes are frequently dependent on access to infrastructure. Access to a potable water supply and environmental sanitation infrastructure are related closely to the incidence of enteric diseases, protein malnutrition in infants, and infant mortality. Adequate transportation infrastructure and the provision of physical health amenities, such as clinics, are closely related to the proportion of women with access to adequate pre-natal and post-natal care and as a consequence, to the maternal death rate. While considerations of health and infrastructure are distinct, it is important to bear in mind the connections between them.

### 5.7.3 HEALTH

**The general trend of declining poverty levels in the LMB has been driven by, and contributed to improving health conditions.** MRC (2010) concludes that progress towards the health-related Millennium Development Goals (MDGs)[41] is either "on track" or "possible to achieve" in the LMB countries. Since the 1960s, all four countries have seen dramatic improvements

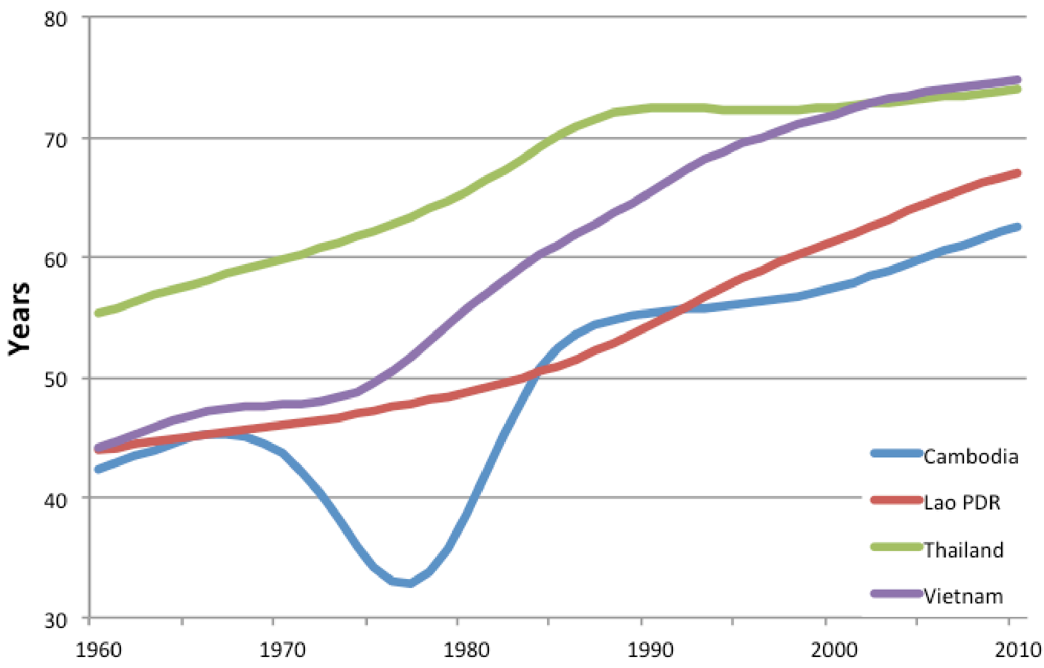
---

[41] The health-related MDGs include: "Halve the proportion of people who suffer from hunger", "Reduce by two-thirds, between 1990 and 2015, the maternal mortality ratio", "Reduce by two-thirds, between 1990 and 2015, the under-five mortality ratio", "Achieve, by 2015, universal access to reproductive health", "Have halted by 2015 and begun to reverse the spread of HIV/AIDS", "Achieve, by 2010, universal access to treatment for HIV/AIDS for all those who need it", "Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases".

in life expectancy. The effects of widespread regional conflict are clearly visible in the life expectancy trends of Cambodia and Vietnam in particular and to a lesser extent Lao PDR. Progress made by Vietnam is particularly impressive, which has moved from a level comparable to Cambodia and Lao PDR in the 1960s to overtake Thailand by the mid-2000s (Figure 5-6).

**Figure 5-6: Life expectancy at birth in LMB countries (1960–2011)**

*Source: WDI 2013*

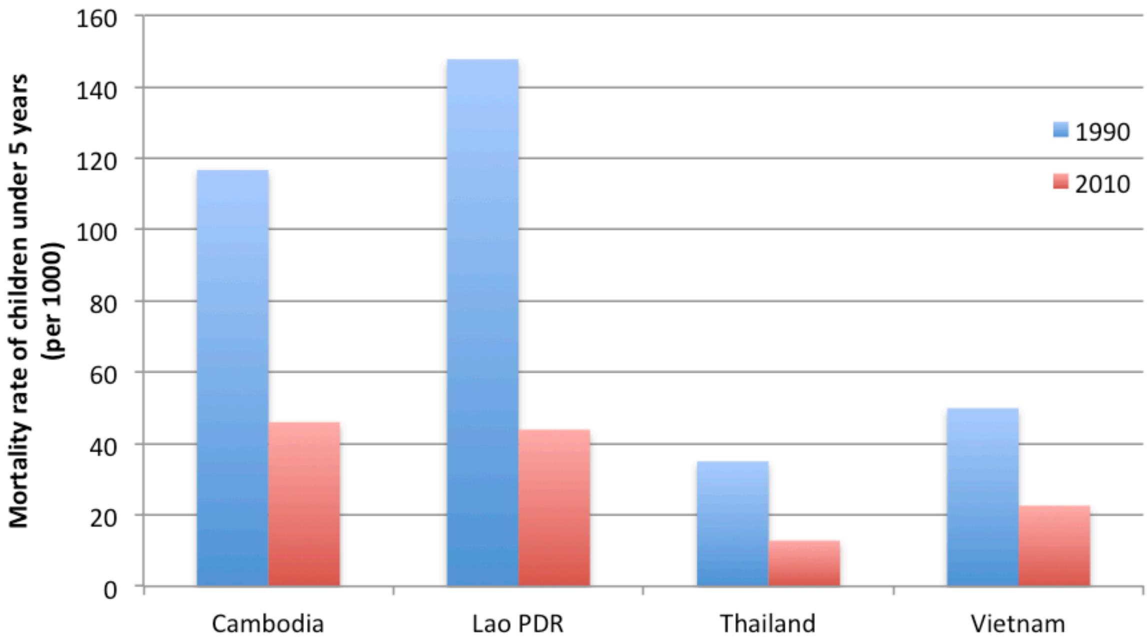



**Lao PDR and Cambodia continue to lag well behind Thailand and Vietnam and this is reflected in other health indicators.** For example, in 2008, in Cambodia and Lao PDR the proportion of deaths attributable to communicable diseases, maternal, prenatal, and nutritional conditions remained at 47% and 41% of deaths respectively (i.e., largely preventable diseases affecting mothers and infants disproportionately associated with poor environmental sanitation and limited access to basic healthcare). In Thailand and Vietnam the proportion of deaths attributable to those causes was 17% and 16% respectively. By contrast, non-communicable diseases, such as cancer, cardiovascular disease, and other conditions associated with old age were much higher in Thailand and Vietnam.

Declining child mortality rates also reflect the overall progress that has been made in the health sector (Figure 5-7). However, the profiles of hotspot provinces in this study show that some areas still experience very high child mortality rates. A recent survey across half the districts of Khammouan province in Lao PDR found that, on average, mothers had lost at least one child before the age of five. Certain districts of Mondulkiri Province in Cambodia reported mortality rates for children under five years of 20% in 2011.

**Figure 5-7: Mortality rates of children under 5 in the LMB (1990 and 2010)**

*Source: WDI 2013*




In terms of the level of health access (e.g., hospitals, beds, and physicians) the situation is better in Thailand, and to a lesser extent Vietnam, than in Cambodia and Lao PDR. Once again, **health coverage is not uniform across these countries, with access to health services much better in urban and lowland areas. Ethnic minority groups in remote upland areas in particular tend to have much poorer access to health services.**

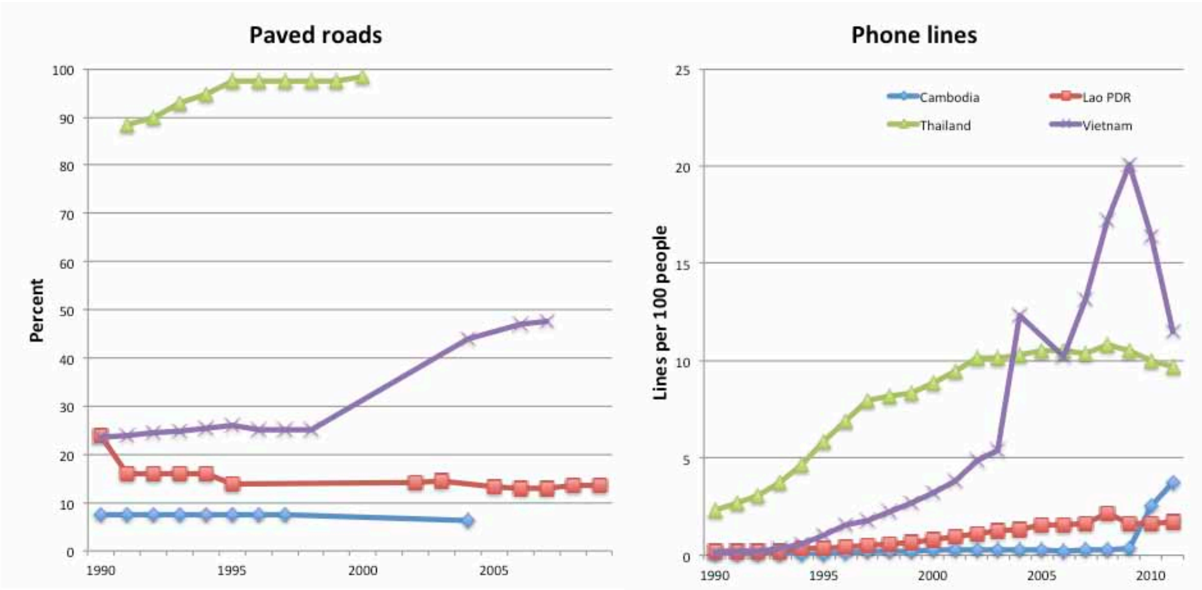
### 5.7.4 RURAL INFRASTRUCTURE

Similar to the health sector, **the level and quality of infrastructure across the region varies greatly between and within countries of the LMB**. For example, the relatively advanced transport infrastructure of the Isan region in Thailand is in stark contrast to the unpaved and sparse road network in upland areas of Lao PDR and Cambodia, reflected in the national statistics. The figures on the number of phone lines per 100 people gives some indication of the penetration of modern telecommunications technology (Figure 5-8).[42] Similar trends to those in health are clear. **Thailand has a significantly higher level of infrastructure development, Vietnam has been going through a rapid transition since the mid-1990s, and Cambodia and Lao PDR lag behind.**

[42] This comes with the important caveat that mobile phones obviate the necessity for fixed line communications technology visible in recent declines in traditional fixed lines in Thailand and Vietnam.

**Figure 5-8: Proportion of roads paved and phone lines per 100 people (1990–2010)**

*Source: WDI 2013*




The variation in access to infrastructure is illustrated well by the rural-urban disparity in access to safe drinking water and improved sanitation facilities (Table 31). Also, measuring aggregate health conditions tends to obscure the real situation on the ground: the indicators "access to an improved water source" and "access to an improved sanitation facility" vastly over-estimate household access to safe drinking water (Bain et al. 2012, Onda et al. 2012).

**Table 31: Access to improved water source and improved sanitation facilities in the LMB**

| Country | Access to an improved water source | | Access to improved sanitation facilities | |
|---|---|---|---|---|
| | 1994 | 2010 | 1994 | 2010 |
| **Cambodia** | 32% | 64% | 9% | 31% |
| ***Urban*** | 48% | 87% | 36% | 73% |
| ***Rural*** | 29% | 58% | 5% | 20% |
| **Lao PDR** | 39% | 67% | 16% | 63% |
| ***Urban*** | 75% | 77% | 58% | 89% |
| ***Rural*** | 32% | 62% | 8% | 50% |
| **Thailand** | 88% | 96% | 88% | 96% |
| ***Urban*** | 96% | 97% | 94% | 95% |
| ***Rural*** | 85% | 95% | 85% | 96% |
| **Vietnam** | 65% | 95% | 44% | 76% |
| ***Urban*** | 90% | 99% | 69% | 94% |
| ***Rural*** | 65% | 95% | 37% | 68% |

*Source: WDI 2013*

The extent of irrigation infrastructure varies greatly between the LMB countries. Table 32 shows that Thailand and Vietnam have extensive irrigation coverage, whereas Cambodia and Lao PDR do not. The presence of irrigation infrastructure is generally a major determinant of agricultural productivity, allowing multiple and more abundant crops over the course of a year than if water delivery relied solely on rainfall. This is particularly important in terms of dry season crops. However, irrigation infrastructure is expensive to build and requires extensive maintenance; it is understandable therefore that extensive irrigation is both an indicator and driver of higher income and food security.

**Table 32: Irrigation in LMB countries, 2010**

| Country | Total area of irrigated land (1000 ha) | Total area of agricultural land (1000 ha) | % of agricultural land under irrigation |
|---|---|---|---|
| **Cambodia** | 354 | 5,655 | 6.3 |
| **Lao PDR** | 310 | 2,378 | 13 |
| **Thailand** | 6,415 | 21,060 | 30.5 |
| **Vietnam** | 4,600 | 10,768 | 42.7 |

*Source: FAO 2013. Figures are for 2010*

Lao PDR has a relatively high level of access to electricity for its income level; in fact, as of 2012, 80.3% of households are electrified (LIRE 2013) (Table 33). A key causal factor explaining Cambodia's low electrification rate is some of the highest electricity prices globally, as well as the related issue of low levels of government investment. By contrast, electrification in Thailand and Vietnam is almost universal, largely as a result of dedicated government programs.

**Table 33: Electrification rates of LMB countries, 2009**

| Country | Electrification rate | Population without access to electricity (millions) |
|---|---|---|
| **Cambodia** | 24% | 11.3 |
| **Lao PDR** | 55% | 2.6 |
| **Thailand** | 99.3% | 0.5 |
| **Vietnam** | 97.6% | 2.1 |

*Source: IEA 2013. More recent data indicates a much higher electrification rate for LAO PDR of roughly 80% (LIRE 2013).*

**The overall level of poverty in a particular location in the LMB is indicative of the overall level and quality of rural infrastructure** (i.e., comprising road networks, bridges, irrigation, water supply, household dwellings, municipal buildings, etc.). Remote rural locations with poor communities are generally the areas with the lowest levels of infrastructure.

## 5.7.5 VULNERABILITY ASSESSMENT

### 5.7.5.1 Health

**The key areas of community health identified as highly vulnerable to climate change are vector-borne and water–borne disease control, and maternal and child health.** In terms of specific climate change threats, the most prominent across hotspot provinces were temperature rise, flooding, flash flooding, and landslides. The hotspot provinces with greatest overall vulnerability in the health sector are Mondulkiri and Gia Lai.

#### Vector-borne and water-borne disease

Climate change is projected to cause a marked increase in the incidence and extent of flooding in many parts of the basin. Floods and associated extreme rainfall create the conditions for the spread of water-borne and vector-borne disease, restricted access to freshwater and food, inundation of unsafe sanitation facilities, and isolation from health services. Notwithstanding advances in health coverage over recent years such as improved immunization coverage, such diseases remain prominent development issues in the LMB that cause death, incapacitation, and have long-lasting impacts on poverty and food security. And they are not restricted to the poorest areas of the basin: outbreaks of water-borne disease were widespread during recent floods in Thailand and Vietnam. **Subjecting today's socio-economic conditions to future climate projections would see an increase in the incidence and extent of water- and vector-borne diseases.** A principal reason communities are exposed to these problems is their habitation of fertile riparian areas; this pattern is fundamental to rural livelihoods and will persist into the future. *Floodplain, Delta, and Lowland plains and plateaus zones of the basin are considered to have the highest vulnerability to this particular impact.*

### Maternal and child health

**Maternal and child health are major contemporary issues in remote parts of the basin that would deteriorate further under projected climate change**. These issues are particularly prominent in Cambodia and Lao PDR and/or amongst ethnic minority groups with weaker access to social services. For example, certain villages of Khammouan (Lao PDR) report an average mortality rate of one child per mother; in Mondulkiri (Cambodia) province maternal mortality in 2011 was reported to be 7.2% within one month of birth—a major cause is the lack of access to skilled health attendants in remote areas. Water- and vector-borne disease is mostly associated with flooding. Maternal and child health are exposed to a wider range of other climate change impacts, such as heat stress, greater incidence of droughts, death or injury associated with landslides and flash floods, as well as flooding. The combination of these many impacts with the greater susceptibility of maternal and child health to adverse shifts in food security, as well as the poor state of current conditions in many rural areas, renders this health issue a key component of climate change vulnerability for the basin as a whole. *Despite this broad significance, remote areas of the basin, particularly the Forest uplands zone, are considered to be most vulnerable to increased maternal and child health problems.*

### Overview of threats and impacts by province and livelihood zone – Health

**The most prominent climate threats to human health identified across hotspot provinces were temperature rise, flooding, flash flooding, and landslides.** Overall, the neighboring provinces of Mondulkiri and Gia Lai were identified as the most vulnerable provinces. A key projected threat in these provinces is an increase in average maximum temperature of 3°C to 4°C that would generate heat stress conditions for several months of the year. Another key projected threat is higher rainfall during the rainy season increasing the extent and severity of flooding, flash flooding, and landslides across all the hotspot provinces.

**The vulnerability assessments for health identified certain high to very high vulnerabilities within particular livelihood zones: temperature rise in *Lowland plains and plateaus*; flooding in *Floodplain*, *Delta*, and *Lowland plains and plateaus*; flash floods and landslides in *Intensively-used uplands* and *Forested uplands*** (Table 34).

**Table 34: Vulnerability assessments for health by threat, province, and livelihood zone**

| Province/ Livelihood Zone | Temperature | Precipitation | Drought | Flooding | Flash floods | Landslides |
|---|---|---|---|---|---|---|
| **Chiang Rai** | | | | | | |
| *Intensively used uplands* | Medium | Medium | Low | Medium | High | High |
| *Lowland plains and plateaus* | High | Medium | Medium | High | Medium | Medium |
| *Floodplain* | High | Medium | Low | Very High | Medium | Low |
| **Gia Lai** | | | | | | |
| *Intensively used uplands* | Very High | Medium | Low | Medium | Very High | Very High |
| *Lowland plains and plateaus* | High | Medium | Low | Medium | Medium | Medium |
| **Khammouane** | | | | | | |
| *Forested uplands* | Medium | Low | Low | Medium | Very High | Very High |
| *Lowland plains and plateaus* | Medium | Low | Medium | Very High | High | High |
| *Floodplain* | Medium | Low | Low | Very High | Medium | Medium |
| **KienGiang** | | | | | | |
| *Delta* | High | Low | Medium | Very High | Low | Low |
| **Mondulkiri** | | | | | | |
| *Forested uplands* | Very High | Medium | High | Medium | High | High |
| *Lowland plains and plateaus* | Very High | Medium | Very High | Very High | Medium | Medium |

### 5.7.5.2 Rural infrastructure

**Two key areas of the rural infrastructure sector are identified as highly vulnerable to climate change: roads and water supply infrastructure.** The most prominent climate threats to rural infrastructure across hotspot provinces are flooding, flash flooding, and landslides.

#### Rural roads

**Rural road networks are critical infrastructure highly exposed to climate change in both upland and lowland areas of the LMB**. Two main factors affect road exposure to climate change impacts: (i) the quality of road construction, and (ii) the location of roads. In upland areas of the LMB, particularly *Forested uplands*, much of the road network is unsealed and structurally unstable. This makes them highly susceptible to damage from flash floods. The location of many roads on sloping land increases exposure to landslides as well as flash flood events. The issue of exposure in sloping areas is particularly serious in *Intensively-used uplands* where deforestation has caused erosion and slope instability. In *Floodplain*, *Delta,* and *Lowland plains and plateaus* zones the proximity of roads to rivers and lakes makes them susceptible to floods. In addition, the lack of strong embankments and unsealed road surfaces in remote and/or poor areas, such as areas of Mondulkiri and Khammouan, heighten the impacts when flooding occurs.

Future amplification of extreme events will magnify the instances of road degradation by flood waters, road inaccessibility due to water coverage, and road destruction by landslides and flash floods. Loss of road access reduces or prevents access to markets and external health facilities. Such constraints are significant for rural livelihoods during normal periods, but they are even more important in emergency situations following extreme weather events.

### Water supply infrastructure

**The impact of climate change on irrigation and drinking water infrastructure has the capacity to drive communities back into prolonged poverty and food insecurity.** Water supply infrastructure is susceptible to a range of extreme weather threats: degradation and, in the case of groundwater wells, contamination by prolonged flooding; destruction by sudden violent events such as landslides; and inundation by sea level rise and storm surges. The basin is faced with an amplification of historical events and associated damages that already impact the stock of rural infrastructure.

Irrigation dams and canals, groundwater bores, water pump equipment, and the like are expensive to purchase, maintain, and repair. Damage to such infrastructure has prolonged and far-reaching impacts. It undermines even relatively prosperous communities that enjoy improved access to water supply threatening reversion back into poverty. Groundwater is a major source of drinking water across the region and the lack of access to these supplies during flood events has serious ramifications for the spread of water-borne disease.

In upland areas (*Forested uplands* and *Intensively-used uplands* zones), water supply infrastructure is considered to be most exposed to violent events such as flash floods and landslides. In low altitude areas (*Floodplain*, *Lowland plains and plateaus*, and *Delta* zones), the key issue is flooding (or in coastal areas freshwater flooding combined with seawater inundation) causing direct physical damage, loss of access, or, in the case of uncovered groundwater wells, contamination after floodwaters have receded.

### Overview of threats and impacts by province and livelihood zone – Infrastructure

**The most prominent threats to infrastructure identified across hotspot provinces were flooding, flash flooding, and landslides.** The distribution of overall climate change threat to infrastructure by province is largely dependent on livelihood zone composition (Table 35). Flash floods and landslides were identified as key issues in upland areas, with flooding the major threat in lowland areas.

**Table 35: Vulnerability assessments for infrastructure by threat, province, and livelihood zone**

| **Province/** Livelihood Zone | Precipitation | Flooding | Flash floods | Landslides |
|---|---|---|---|---|
| **Chiang Rai** | | | | |
| *Intensively used uplands* | Medium | Medium | High | High |
| *Lowland plains and plateaus* | Low | High | Medium | Medium |
| *Floodplain* | Low | Very High | Medium | Low |
| **Gia Lai** | | | | |
| *Intensively used uplands* | Medium | Medium | Very High | Very High |
| *Lowland plains and plateaus* | Low | High | High | High |
| **Khammouane** | | | | |
| *Forested uplands* | Medium | Medium | Very High | Very High |
| *Lowland plains and plateaus* | Medium | Very High | Medium | High |
| *Floodplain* | Medium | Very High | Medium | Medium |
| **KienGiang** | | | | |
| *Delta* | Medium | Very High | Low | Low |
| **Mondulkiri** | | | | |
| *Forested uplands* | Medium | Medium | High | Very High |
| *Lowland plains and plateaus* | Medium | Very High | Medium | Medium |

Aside from roads and water supply infrastructure a range of other significant infrastructure were identified as vulnerable to climate change, such as damage to household buildings, e.g., grain storage; lack of access or damage to health facilities, markets, and other communal infrastructure; and damage or destruction of bridges and river landing sites for boats.

## Summary of aggregate climate change vulnerability by province and livelihood zone

Table 36 summarizes the overall climate threat posed to the health and infrastructure sectors by province and livelihood zone. This aggregation combines the information in the tables earlier in this section.

**Table 36: Summary vulnerability assessments for health and infrastructure by province and livelihood zone**[43]

| **Province /** *Livelihood Zone* | **Health** | **Infrastructure** |
|---|---|---|
| **Chiang Rai** | High | High |
| **Gia Lai** | High | High |
| **Khammouan** | Very High | Very High |
| **Kien Giang** / *Delta* | High | Very High |
| **Mondulkiri** / | Very High | Very High |
| *Forested uplands* | Very High | Very High |
| *Intensively-used uplands* | High | Very High |
| *Lowland plains and plateaus* | High | High |
| *Floodplain* | High | Very High |

[43] The assessments in the table represent summaries for each livelihood zone across all the provinces in which they occur. Each row represents an aggregate assessment for each livelihood zone for health/infrastructure. The summary assessments for provinces represent summaries across all the livelihood zones in a particular province.

## 5.8 CROSS-SECTOR ANALYSIS – A CASE STUDY

Integrated assessment of climate change in one area or livelihood zone requires site-specific knowledge. The basin-wide nature of this study precludes systematic and detailed analysis from a cross-sector perspective in each of the hotspot provinces. Throughout this report, cross-sector linkages have been highlighted when identified in the broad vulnerability assessments and adaptation planning. In the following section on Mondulkiri Province a review of a number of impacts from different sectors bring potential linkages into sharper focus. This desk-based case study was conducted to illustrate the importance of taking a cross-sector and spatially-integrated approach to vulnerability assessments and adaptation planning and implementation.

### 5.8.1 IMPACT OF TEMPERATURE INCREASE ON LIVELIHOODS IN MONDULKIRI

#### 5.8.1.1 Overview

The *Lowland plains and plateaus* zone of Mondulkiri is sparsely populated and has one of the highest levels of poverty in the LMB. Over 80% of households live in rural areas and the main livelihood activities are agriculture and the collection of NTFPs. In riparian areas subsistence-based fishing is also prominent. Natural resources are a principal component of livelihoods; although deforestation for logging, mining, or agricultural land concessions is reducing availability and access.

Food insecurity in the province occurs frequently and often on a seasonal basis. The living conditions of the rural population are poor across a range of health and other social indicators. For example, in 2010 maternal mortality within 1 month of birth was estimated at 7.2%. The quality and incidence of rural infrastructure is generally low: a high proportion of households use surface water for drinking; irrigation infrastructure is not available to most communities; and many become isolated during the wet season due to the poor quality of roads.

Previous experience with climate-related natural hazards in Mondulkiri demonstrates the high vulnerability of the population to climate change (Figure 5-9). In recent years, extreme floods, droughts, and insect infestations have all had serious impacts on welfare.

#### 5.8.1.2 Projected climate change impacts by sector and examples of linkages

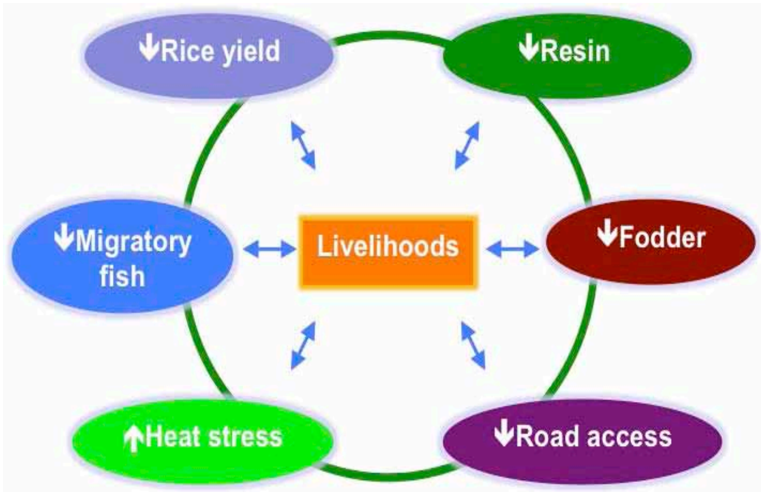
**Agriculture:** The province will experience a 3% fall in rainfed rice yield due to higher temperatures. Also, expanding cassava crops will become highly vulnerable to increased rainfall during the wet season. Extreme events such as storms and excessive rainfall will be a more significant threat and will significantly impact rice, soya, and cassava yields leading to an overall reduction in food security and household **health**, as well as placing more pressure on exploitation of **NTFPs** for food. Reduced cassava yields will also reduce **livestoc**k feed availability.

**NTFPs:** The resin tree (*Dipterocarpus alatus*) is expected to be highly vulnerable to increased temperatures with direct impacts on reproductive rate. Resins are an important source of cash income that support food security and **health**, as well as investments in **livestock** and household **infrastructure** (e.g., grain storage). Earthworms that are critical in maintaining the health of the extensive trapeang (watering-hole) ecosystems are vulnerable to projected high temperatures and reduced soil moisture. Earthworms are a keystone species for the trapeang ecosystems that support other **NTFPs** and **livestock** as well as provisioning surrounding agriculture.

**Livestock:** Higher incidence of drought at the end of the dry season/beginning of wet season is projected to decrease feed availability (including cassava) and livestock health. Higher incidence of flash floods may cause livestock fatalities. Livestock are an important source of household savings and emergency income when crops fail or following extreme events. Loss of this buffer will affect food security and **health**, place greater strain on **fisheries** as a source of protein, and reduce the capacity to invest in **agriculture** for subsequent seasons.

**Fisheries:** The province is expecting increased temperature during the dry season which could lead to a decline of migratory white fish that are an important seasonal harvest sustaining subsistence communities throughout the year. Reduced surplus during migrations requires increased fishing effort during other seasons, which reduces the time that can be devoted to **agriculture** and **NTFP** harvesting.

**Figure 5-9: Climate change impacts on livelihoods in the *Lowland plains and plateaus* zone of Mondulkiri Province, Cambodia**




**Health:** The projected increased high temperatures (some never before experienced in the province) will generate heat stress conditions for several months during the dry season. Illness due to heat stress reduces productivity of labor in other sectors, such as **agriculture** and **NTFP collection**.

**Infrastructure:** More extreme flooding is expected to damage roads and reduce access to and from communities during and after floods. Limited road access reduces capacity to obtain external food supplies during stress and may be a driver of water-borne disease; therefore adverse **health** consequences are likely. Also, access to **NTFPs** would be reduced.

Those linkages are examples drawn from the study team's broad understanding of livelihoods within the *Lowlands plains and plateaus* zone of Mondulkiri. A more complete analysis would require detailed local survey and consultation. The examples are restricted to some second order impacts, and not the third or fourth order impacts that would cycle through the livelihood system. Those multiplier and cumulative impacts are at the heart of livelihood vulnerability to climate change. Communities will be exposed to shifts in multiple sectors. The shifts will have direct and secondary impacts which feedback to influence the livelihood system again. Each of the risks that climate change poses to a community in the LMB should not be treated in isolation; they must be considered from a systems perspective.

### 5.8.2 GENDER, CHILDREN, AND VULNERABLE GROUPS

An important crosscutting issue is the differentiated impacts of climate change on women, children, and vulnerable groups. Rural communities and households in the LMB are not homogenous entities. Disparities exist in terms of assets, access to services and resources, and income opportunities. Those considerations are a central focus of rural poverty assessments, yet they require even greater prominence in climate change assessments because existing social disparities are exacerbated as a result of climate shocks.

**Vulnerable and disempowered groups in the LMB are more affected by negative climate change impacts and have less capacity to adapt to those impacts.** The following discussion on the origins and consequences of those impacts focuses on gender issues as women generally act as the primary caregivers for children, the sick, and the elderly. A later sub-section provides a separate discussion on the implications for ethnic minority groups.

#### 5.8.2.1 Gender

**The "gender gap" ensures that women are more exposed to the negative consequences of climate change**. On a global basis, social norms systematically limit the options for women (CGIAR/FAO 2010). There are gaps between the opportunities afforded to men and women due to cultural perceptions of abilities and appropriate responsibilities. Across the LMB women play defined household roles that limit their access to cash income, such as domestic duties and subsistence-based gathering. Frequently, lack of power in community governance or household decision-making prevents women from pursuing welfare-improving activities. These factors are often exacerbated by differential access to assets, such as land and education and services such as credit. In the face of adversity, such gaps amplify the loss felt from damage to what limited income or assets are controlled.

There is a wide range of reasons why women can be more adversely affected by climate change impacts.[44] Many of the potential gender-differentiated impacts are indirect, and their manifestation would be highly context specific (Goh 2012).

*Agricultural production* – Lowered agricultural production will have varied effects depending on the roles that men and women take in production. Women are associated with labor-intensive tasks (such as planting and tending crops) and their workload is likely to increase with greater climate variability. If women hold primary responsibility for livestock production, losses in that area may affect their income generation. There is a discrepancy along gender lines concerning access to the information and inputs that are required in a changing climate. For example, in the delta often it is only men who participate in agricultural extension programs (Nguyen et al. 2010).

*Food security* – Woman are the main providers of household meals. Food scarcity due to climate events will entail a greater burden on women to feed a family, in terms of labor but also psychological stress. Globally there often exist gender inequalities in food distribution, with men and boys favored over women and girls. In the presence of scarcity due to climate shifts, receiving less nutrition places women in a vulnerable situation in terms of disease and also the productivity of all their other activities.

*Health* – Women are typically the primary caregivers for the sick. Greater incidence of illness in other household members due to, for example, higher temperatures places a greater burden on women that limits their capacity to fill other household tasks and income-generating activities. Regarding women's direct health concerns, water scarcity is related to higher rates of gynecological disease. Women spend much of their time in and around the family dwelling where stagnant water is present, a major breeding ground for the disease vectors that are expected to increase in abundance and extent due to climate change in many areas of the LMB. Finally, for physiological reasons pregnant women are generally more vulnerable to climate-related disease epidemics.

*Water and energy resources* – In many cultures across the LMB women are charged with collecting water and wood for household use. Climate change may impact on their ability to fulfill those tasks through drought, floods, and other phenomena that prevent access. In response, women generally have to travel further to collect sufficient quantities and this reduces the time available to spend on other activities and may induce fatigue that impacts on health and well-being.

---

[44] See CGIAR/FAO (2010), Brody et al. (2008), Goh (2012), Nellemann et al. (2011), UNDP (2010), WHO (2011). The following discussion draws from case study examples and analysis contained in these references.

*Migration* – Men are often more mobile and able to migrate when weather events affect their livelihood activities. Women, on the other hand, are often required to remain in the family household and care for children and other relatives. Without a steady stream of remittances from men, this situation can require women to fulfill household and livelihood duties as the sole bread winner.

These potential impacts point to major issues with regard to gender and climate change in the LMB. Yet, substantive, specific conclusions with regard to gender-based climate change impacts will require dedicated research at the local level. First, because gender-specific climate impacts within a community or household are influenced by specific cultural norms. There are over 70 different ethnic groups in the LMB (Hook et al. 2006) and social dynamics vary greatly to the extent that gender roles can vary from one village to the next (Nghia 2000). Second, men and women play "gender sequential roles", that is they fulfill activities at different stages of production, such as men preparing rice fields and women planting. Identifying overall impacts of climate change on women in the context of complex socio-cultural systems requires a more detailed analysis of indirect impacts.

Keeping those caveats in mind, Table 37 illustrates the potential gender implications of climate change impacts identified in this study for different sectors and hotspots.

**Table 37: Gender implications of climate change impacts**

| Livelihood Sector | Hotspot Province | Climate Change Impact(s) | Potential Gender Implications |
|---|---|---|---|
| Agriculture | Kien Giang | Saline intrusion due to sea level rise and storm surges leading to lower rice production | Saline intrusion significantly reduces the productivity and/or viability of rice farming. In Kien Giang women are employed as laborers in rice fields. Lower productivity may increase their workload. Shrimp farming may be a viable alternative on saline-affected land. Male labor is dominant in shrimp farming as it is a more physically and mentally demanding activity and it is culturally perceived to be more appropriate for men. Shifting landuse from rice to shrimp would reduce women's income opportunities (Nguyen et al. 2010). |
| Fisheries | Chiang Rai | Increased water temperature and decreased water availability reducing aquaculture yields | On the Ping River in Chiang Rai, men and women share an equal role in the management of aquaculture. Engagement in aquaculture has contributed to empowerment of women within households and the community generally (Lebel et al. 2009). Lower aquaculture productivity may reduce the importance of this activity to household livelihoods and diminish the associated authority that women had previously received. |
| Natural Systems | Kien Giang | Sea level rise reducing availability of NTFPs | In Kien Giang women take the main role in gathering non-timber forest products for food and medicinal purposes (Nguyen et al. 2010). Sea level rise is reducing the habitat of mangrove ecosystems. Reduced access to NTFPs would reduce women's access to NTFPs for subsistence purposes, as well as to income opportunities from arising from commercial activities. |
| Livestock | Gia Lai | Temperature rise reducing the productivity of pigs and possibly raising mortality | Women take the lead role in raising pigs as this activity normally occurs around the home (Tisdell 2010). Lower pig productivity and higher mortality may reduce the income-earning potential of women. Pigs are also an important form of savings and an asset in times of emergency. Loss of these positive assets may reduce the capacity of women to provide food for their family in times of scarcity. |
| Socio-economics | Mondulkiri | Heat stress-related illness and decreased water availability increasing the burden of caring for the sick and increasing women's exposure to illness | The health situation in Mondulkiri is very poor.[45] Child mortality under 5 years is up to 21% in remote districts. Maternal mortality within 1 month is 7.2%. Higher temperatures and lower water availability will increase the already high prevalence of disease. Healthy women will be required to spend more time caring for the sick and devote less time to other productive activities. Women, particularly pregnant women, will be exposed to higher health risks. |

### 5.8.2.2 Other Vulnerable Groups

**Across remote rural areas of the LMB there are a large number of ethnic minority groups that are among the poorest of the poor and highly exposed to climate change.** Although invariably involved in some commercial activities, ethnic communities are generally far from markets and the income opportunities they support. A heavy reliance on natural resources for subsistence means that ecosystem shifts due to climate change will have a large impact on groups

[45] See the socio-economic theme report for further details and references.

like the Phnong in Mondulkiri.  In times of need, financial and institutional barriers limit access to social services for ethnic groups in Gia Lai.  Language barriers prevent some Khmer and Cham households in the Mekong Delta from participating in agricultural extension programs, which might enhance their resilience to climate change.

These examples illustrate some of the many factors related to the additional climate change vulnerability of minority groups.  Similar to gender, these issues have to be considered in the specific socio-cultural context of particular communities.  Each of the issues reflects a gap in the opportunities for ethnic minority groups compared to the rest of the population.  This gap increases the likelihood of these groups being adversely affected by climate change and reduces their capacity to respond.

# 6 ADDITIONAL EFFECTS OF DEVELOPMENT ON VULNERABILITY

The approach taken in this study was to assess the status and trends in the targeted systems and areas of the LMB, including past experience with extreme climate and hydrological events. The main drivers and influences of those trends—for example, forest loss, agricultural intensification, and migration to remaining natural areas – were identified and documented in the six theme volumes prepared for this study. The study found that development trends are transforming the LMB ecology and economies—and consequently the capacity of natural systems to continue playing such an important provisioning role in farming systems. The pace and scale of development is so significant that it becomes difficult to discern the impacts of climate change on livelihoods against the background noise of other change.

There are two approaches the study has taken to overcome that challenge. The first was to project climate change far enough into the future so its effects stand out against the backdrop of other influences. The second was to identify the main development drivers of change and associated trends during the baseline assessment and then to "park" that information to be picked up again and considered during adaptation planning. That way, during the assessment phase, impacts and vulnerabilities due to climate change can be defined in isolation without distraction from development forces.

Now is the time to bring back those development influences and to describe and analyze them more fully, so they can be taking into account in Chapter 7 when defining integrated adaptation options for the most vulnerable systems, species, and areas. Adaptation needs to be part of the overall effort to develop in ways that are equitable and ecologically sustainable.

## 6.1 AGRICULTURE

Climate change is one of many drivers influencing the agriculture sector in the LMB. Population growth, change in food diet, hydropower development, agrarian changes, and trends in labor can be considered as local drivers. The sector is also influenced by international market demand for some commodities such as biofuel, rubber, and animal feed. Direct foreign investment in agriculture is another important driver of change in LMB farming systems.

### 6.1.1 POPULATION GROWTH AND CHANGING DIET

**Food demand in the region will continue to rise as populations grow and diets change.** Food demand in the Greater Mekong Subregion[46] will increase by at least 25% by 2050 (Johnston et al. 2010). Governments will have to shape agriculture policies to meet demand and achieve food security goals and reduce malnutrition. The increasing demand for food on the local market and policies to reduce malnutrition will certainly influence the agriculture sector. New food exporter countries such as Vietnam and Thailand, and more recently Cambodia, will have significant influences

[46] GMS cooperation covers China (Yunnan Province and Guangxi Zhuang Autonomous Region), Cambodia, Laos, Myanmar, Thailand, and Vietnam, with a total area of 2,568,600 km$^2$ and a combined population of about 326 million.

on the local market with more production targeting the export market. Liberalization of the Chinese food market away from the food self-sufficiency target will increase imports from neighboring countries to meet the demand for food.

Changes in diet including an increasing demand for food from animal sources, a shift from cereals to non-cereals, and higher consumption of fruits, sugar, and oils will also induce changes in the agricultural sector. Increasing demand for animal products requires more grain as animal feed and correspondingly an increase in grain production. An increase in grain production can be met only with intensification of agriculture and expansion of agriculture land (Brown 2005).

### 6.1.2 AGRICULTURE POLICY

Agriculture provides livelihoods for more than 75% of the LMB population. Policies to develop the sector are central to economic development in all LMB countries. In the past, Thailand and Vietnam strongly supported the sector to drive economic growth and reduce poverty. Vietnam has set a sector target of 4% to 4.5% growth annually and increasing export earnings during the next 10 years (Rutherford et al. 2008). Similarly, Lao PDR has set the agriculture sector as a priority for promotion of investment for 2001–2020. In Cambodia, agricultural expansion and intensification including expansion of expertise are priorities in the Government's Rectangular Strategies (RCG 2004).

**National agriculture policies can have far-reaching impacts on the sector, for example, those supporting and promoting a specific commodity.** In the past decade, support for rubber plantations and development of the rubber industry fundamentally modified northeast Thailand. Thailand is now the number one rubber producer in the world (FAOSTAT 2012), and provinces like Ubon Ratchatani or Surin have large areas of rubber plantations (30,000 ha and 14,000 ha respectively in 2010).

### 6.1.3 CONCESSIONS AND COMMERCIAL CROPS

**Cambodia and Lao PDR have oriented their agriculture development towards promoting private investment and industrial agriculture.** The resulting investment and economic incentives in plantation and concessions has transformed the landscape with plantations of rubber, eucalyptus, oil palms, grains, legumes, and cassava. In Lao PDR, the foreign direct investment in agriculture between 2001 and 2007 reached US$665 million for the development of rubber, eucalyptus, and cassava plantations (Voladet 2008 cited in Johnston et al. 2010). By 2007, the Lao PDR government granted more than 150,000 ha of large-scale concessions for plantations (MPI 2008). In Savannakhet province, more than 20,000 ha have been granted for sugarcane culture, 21,000 ha for cassava culture, and 30,000 ha for eucalyptus plantations.

Similar trends are found in Cambodia. Between 2008 and 2011, the area planted with rubber in Cambodia increased 75%, from 108,000 ha to 188,000 ha. In 2007, US$363 million of foreign investment went to agriculture and agro-industry and land concession covering a total of almost 10,000 ha (MAFF 2009). Direct foreign investments target tree species, rubber, and oil palm. Those concessions will bring extensive new areas into production and a new face to the agriculture sector; with its benefits and also challenges for ecological sustainability, economic efficiency, and social equity.

### 6.1.4 INTERNATIONAL MARKET DEMAND

**The food crisis with a peak demand for agriculture food commodities in 2008 reflects the acute sector dependence on international trade.** Climate related shortfalls in production, increasing demand for certain commodities for biofuel instead of food, and demand for livestock feed are shaping the international and regional demand for the main agriculture commodities.

The recent expansion of cassava is mostly driven by market demand. For example, in Thailand the price charged by producers of cassava increased from US$15.7 per ton to US$57.9 per ton between 2000 and 2008 (FAOSTAT 2012). Cambodia's cassava production is mostly for export to Thailand and Vietnam, where processing factories have generated high demand for the raw product. In Lao PDR, the development of a processing plant for starch from cassava increased the cultivated area of cassava in three provinces from 2,000 ha in 2008 to 13,000 ha in 2012. The processing plant is contract farming with more than 2,000 families covering an area of 7,600 ha. Similar examples of contract farming for eucalyptus plantations are found in Southern Lao PDR.

### 6.1.5 URBANIZATION AND MECHANIZATION OF LABOR

The region is characterized by the emergence of megacities such as Bangkok, Ho Chi Minh City and Hanoi. Urbanization is a common trend in all the countries of the LMB, with now less than 80% of the population living in rural areas (more than 80% in 1990 in Lao PDR, Vietnam, and Cambodia – MRC 2010). In 2010, the urban population annual growth rate in Vietnam, Cambodia, and Lao PDR was 2.72%, 3.90%, and 4.8 % respectively. In Thailand it was 1.61% (World Bank 2012).

**The urbanization process has a major effect on rural and agricultural development**. Urbanization brings with it centralization of markets and services as well as seasonal and permanent migration of agriculture labor to cities. Urbanization also creates demand for peri-urban agricultural farming systems to feed the cities. Urbanization leads to conflict for landuse as agricultural areas are swallowed up by expanding settlements, industrial zones, and infrastructure.

Economic growth of non-agricultural sectors absorbs an increasing share of the rural population and helps to diversify rural income. Diversification of livelihoods and a shift of household income to non-farm sources is a trend observed in increasing areas of the LMB like northeast Thailand. Also, shortage of agriculture labor is generating labor-saving strategies within the agriculture sector with increasing mechanization and direct seeding for rice crops.

### 6.1.6 HYDROPOWER DEVELOPMENT

The Mekong Basin is one of the most active regions in the world for hydropower development. In the upper basin, China is implementing a cascade of up to eight projects (with 17 under consideration), which will significantly redistribute flow from the wet to the dry season. In the LMB, there are 136 existing, under construction, and potential large-scale tributary hydropower projects (MRC hydropower database)—more than 70% are in Lao PDR.

**The development of extensive networks and cascades of hydropower reservoirs will have far reaching impacts on agriculture in the LMB.** In some areas it might reduce threats to farms in the rainy season from flashfloods and flooding by regulating flow. Downstream irrigation is another potential benefit from multipurpose hydropower reservoirs. Nam Theum 2 hydropower dam or the THPC hydropower dam in Lao PDR are providing for multiple uses of reservoir water and resources. Hydropower development is expected to have increasing negative impacts on fisheries productivity, which will place added pressure on the agriculture sector to offset those losses (ICEM 2012).

**Competition for water between farmers and electricity producers could become a significant concern throughout the region.** Water flow will be re-distributed throughout the year with more water in the dry season and less water flow in the rainy season. Release of water in the dry season can increase irrigation potential. However water used in agriculture will be lost for downstream hydropower development and might generate conflict between hydropower and irrigation development within the Mekong Basin and its cascades of hydropower reservoirs**.**

### 6.1.7 RELATIVE IMPACT OF CLIMATE CHANGE COMPARED TO OTHER DRIVERS

The drivers of change in agriculture briefly explained and characterized in this section have wide-ranging effects on the sector. Economic policies, foreign investment, and market demands are drivers shaping and transforming agriculture and the LMB landscape. Climate change is a more subtle driver of change with incremental shifts from year to year and irregular extreme events—its impact can be overshadowed by the other more immediate and dramatic local drivers. For example, *impact on crop yield from climate change was estimated around 3% to 12% for rice crops by 2050, while in the last 15 years in Vietnam total agriculture production has increased by 80%.*

Unlike market prices that can have sudden impacts that may require immediate responses, climate change will have cumulative and multiplier effects, requiring immediate and continuous adjustments in the long term. The cumulative effect of climate change is likely to gain in importance as a force shaping the sector. Table 38 underlines some of the interactions between climate change and other drivers of change in the agriculture sector. In some cases climate change will exacerbate the impact of those other drivers. Population growth, urbanization, better access to mechanization, and international market demand will drive the agriculture sector toward intensification and market-oriented crops. Those monoculture systems might become more vulnerable to climate events, especially for small-scale farmers with limited access to investment. Climate change can exacerbate the vulnerability of certain crops that are cultivated in less suitable areas due to high market demand or specific agriculture policies.

**Table 38: Examples of interaction between climate change and other drivers influencing the agriculture sector**

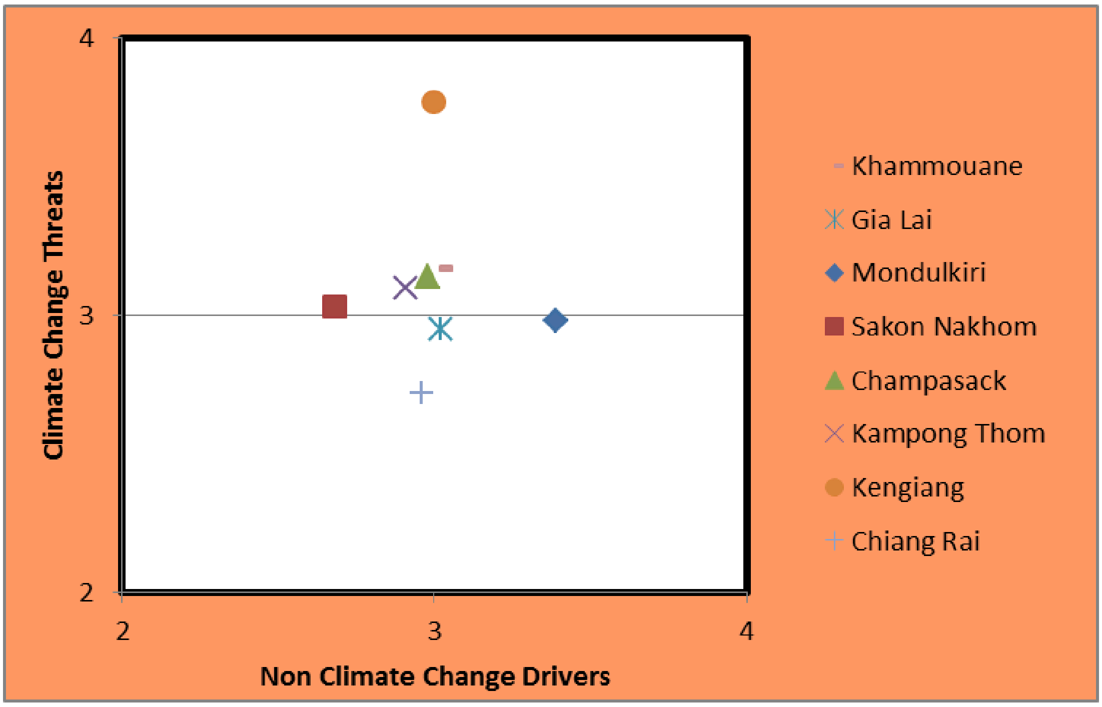
| Drivers of change | Potential changes in the sector | Potential interaction(s) with climate change |
|---|---|---|
| Population growth and food demand and international markets | Intensification of production systems.<br>Shift to non-cereals production system and toward crops related to animal feed. | Regionally, climate change will increase the vulnerability of monoculture systems (maize, sugarcane, soya, cassava) with expansion of crops in less suitable areas where vulnerability to climate change is higher. |
| Agriculture policy | Export-oriented crops (rubber or cassava) | Expansion of crops in less suitable areas or absence of shift to another crop in less suitable areas due to agriculture policies can exacerbate their vulnerability—e.g., in the case of cassava in areas with increased rainfall, or rubber cultivation in warmer areas or zones affected by drought. |
| Private concessions | Expansion of cassava, rubber, and eucalyptus plantations for export market | Current concessions for rubber, cassava, or eucalyptus plantations will be less suitable in the future while the increase of temperature will increase the suitability for those crops in higher altitude areas. |
| Urbanization and mechanization of labor | Shortage of labor and access to mechanization, will contribute to intensification of monocropping systems. | Increase vulnerability of conventional monoculture systems which are less flexible and require much higher investments to remain productive. |
| Hydropower | ▪ Change in flow regime and flood patterns—reduce natural fertilization due to sediment deposition after the flood<br>▪ Increased potential for irrigated area | ▪ Exacerbate yield drop in addition to fertility loss<br>▪ Access to irrigation will expand climate change adaptation options with intensification and/or diversification of production. |

Examples of sugarcane or rubber expansion in the region show that those crops are not cultivated in the most suitable areas and are not the crops best suited to their current locations. Those types of discrepancies between landuse and land suitability due to agriculture policies will be exacerbated with climate change.

Hydropower development and its impact on flood regimes will impact traditional systems based on fertilization through sediment deposition during the annual flood. The gap in fertilization will exacerbate the drop in yield due to climate change. Meanwhile, hydropower development can offset some climate change impacts on yield and vulnerability to drought with expanded opportunities for irrigation. At this stage though, most hydropower projects are not planned and managed for multiple uses.

Figure 6-1 ranks the importance of climate change threats and non-climate change drivers for the hotspot provinces. For each province the climate change threats are averaged for the main crops based on the CAM vulnerability assessment. Similarly, the influence of each non-climate change driver is estimated and its importance averaged for the main crops. Figure 6-1 shows that Khammouan, Sakon Nakhon, Champasack, and Kampong Thom have a moderate climate change threat (slightly above 3) for agriculture, while Chiang Rai is less affected by climate change and non-climate change drivers. Kien Giang Province has a high climate change threat with high and very high vulnerability of the rice-based system to salinity intrusion, sea level rise, and increased temperature. Mondulkiri Province is the most influenced by non-climate change related drivers due to the importance of concession and commercial farming in this province.

**Figure 6-1: Threats to the agriculture sector from climate change and non-climate change drivers in the 8 hotspot provinces**




This approach illustrates differences between provinces but ranking the importance of others drivers of change is difficult to assess by province as are the complex interactions between climate change threats and other drivers across the sector.

## 6.2 LIVESTOCK

Alongside expected climate changes the LMB is undergoing significant socio-economic and biophysical changes affecting current and probable future livestock production and consumption and livelihoods derived from livestock in the region.

### 6.2.1 INCREASING DEMAND AND CONSUMPTION OF LIVESTOCK PRODUCTS

For the past 20 years the LMB countries have experienced high GDP per capita growth. Associated with this growth has been an overall increase in household incomes, standards of living, and increasing domestic demand for livestock-derived products. Investment in infrastructure, such as roads and ICT networks, has contributed to rapid improvements in access to markets and market information in much of the LMB, and with it increasing competition for producers.

Globalization and increasing links to global markets, such as Vietnam's accession to the WTO in 2006, are placing downward pressure on prices and subsequent pressure on domestic production. Further, integration with global commodity markets effects input prices with particular significance for more commercial production systems, most notably pigs and poultry at present. Recent grain price instability has had important, largely negative, effects on the more market-oriented livestock production systems.

The emergence and increasing importance of national and multi-national supermarkets in more accessible parts of the LMB is changing consumer behavior, food safety risks, and the nature of livestock value chains (Wong 2007). Rural demographics are changing with increasing urbanization contributing to an aging rural population in much of the LMB.

### 6.2.2 CONCENTRATION OF LIVESTOCK PRODUCTION

Livestock production is concentrating in line with demand, urbanization, economic growth, and market and trade liberalization, a strong trend expected to continue to 2050 (FAO 2011, FAO-AGAL 2005). While small, low-input systems continue to dominate total farms and stock numbers in much of the LMB, commercial units are rapidly expanding in number and total production. In Vietnam and Cambodia, small- and medium-scale commercial pig and poultry units are very significant suppliers of urban markets, particularly in Vietnam. Also, large-scale "industrial" vertically integrated corporate systems are rapidly expanding in number, production volumes, and market share, particularly in urban areas. The Thai chicken sector offers a probable view of the future of livestock production in the region. In Thailand total chicken production is now dominated by large-scale vertically integrated enterprises. Small- and medium-scale commercial poultry production, unable to compete on price, has dwindled leaving a polarized system of low-input diversified "subsistence" producers and large volume integrators.

Current trends in the Basin strongly suggest the following developments in the livestock sector, by country:

**Cambodia:** Small and medium-scale commercial pig and poultry production continue to grow rapidly. Large-scale commercial poultry and to a lesser extent pig production is also growing rapidly and already commands a significant share of urban markets. Beef production is polarized, dominated by low-value local produce and high-value imported products. Market concentration in beef production is unlikely in the foreseeable future.

**Lao PDR:** There is very little commercial production, though small-scale commercial pig and poultry production supplying Vientiane is emerging in surrounding areas. Beef production is heavily dominated by low-input, low-value production systems, which is unlikely to change soon. A small high-value market exists and is supplied almost exclusively by imported beef.

**Thailand:** Poultry is dominated by large-scale integrated production, which is expected to remain the case. Pig production is rapidly concentrating; small-scale commercial units are declining, a trend which will certainly continue. Small commercial beef and dairy production is increasing, and expected to become concentrated in the medium-term.

**Vietnam:** Poultry is rapidly concentrating; small- and medium-scale commercial units are likely to come under increasing pressure from larger producers and imported products. Small and medium commercial systems are expected to peak and decline in the medium-term. Pig production is also concentrating; small commercial units have likely peaked and are expected to concentrate and decline with greater competition from large domestic producers, and possibly imported products. Small-scale commercial beef production is emerging slowly and likely to grow in the medium-term. Dairy has emerged as highly commercialized, vertically integrated enterprises; and production is rapidly increasing.

### 6.2.3 SPREAD OF ANIMAL AND HUMAN DISEASE

Key production issues include animal disease and livestock-related human health issues (e.g., zoonoses, and food quality and safety). The high human and livestock populations, number of livestock-raising households, and the nature of production in the LMB contribute to emerging infectious disease risks; outbreaks and endemic diseases are major concerns.

The increasing market share held by integrators, both national and international, has meant an increasing share of total production is now produced under contract and has led to changes in genotypes and production methods and inputs. The rate and extent of change has varied with Thailand having a longer history of integrated export-oriented production. Vietnam and Cambodia are moving quickly in that direction while change in Lao PDR is less apparent.

There is increasing concern over, and investment in, food safety and quality assurance relating to such issues as pathogens and residues in food products, and stability and quality of supply. The reform is driven by international trade requirements and a desire to unlock new and higher-value markets. Also, an increasing domestic consumer demand for safe, high quality produce is driving regulatory changes both regionally and at national levels. The ASEAN GAP standard as well as national guidelines and standards have been enacted with numerous programs targeting whole chain and nodal safety and certification. These initiatives are affecting costs of production and access to markets for producers and associated value chain actors.

### 6.2.4 INCREASING CONNECTIVITY AND TECHNOLOGICAL INNOVATION

Significant national and international investment in roads, water treatment and supply, electricity, and ICT networks has rapidly increased connectivity in previously remote areas. Parts of the LMB formerly isolated from markets beyond their immediate vicinity are now presented with opportunities to supply higher-value and/or more stable markets. Yet, local farms are increasingly challenged by lower-cost produce from more commercialized production, both domestically and internationally. Increased access to markets is notable throughout the LMB. Cambodia and Lao PDR have seen the most recent rapid increases, though large segments of the populace remain poorly connected.

Increasing access to and use of communication technologies is changing the methods by which producers gather information on markets, both up and downstream, and is altering service access and delivery. New communication tools offer the potential for new approaches to technology transfer. Increasing mechanization, such as the employment of hand tractors and harvesters, is increasing key crop yields and reducing on-farm labor requirements and the need for livestock as a source of traction (Shephard 2010). Rapid mechanization has occurred in the better-connected, more commercially-oriented areas of the LMB such as the delta region of Vietnam, and is slowly changing production methods in more remote areas. Specialization of production is evident in more connected areas supplying urban hubs and exporters, with associated changes in management practices.

Introduction of higher-productivity genotypes has had varied levels of success. When effective, yields have improved and costs of production and disease risks for individual producers have reduced. Recognition of disease concerns has led to numerous programs addressing animal health issues, notably through vaccination programs and access to animal health services, as well as disease surveillance and response capacity building and improved animal husbandry practices.

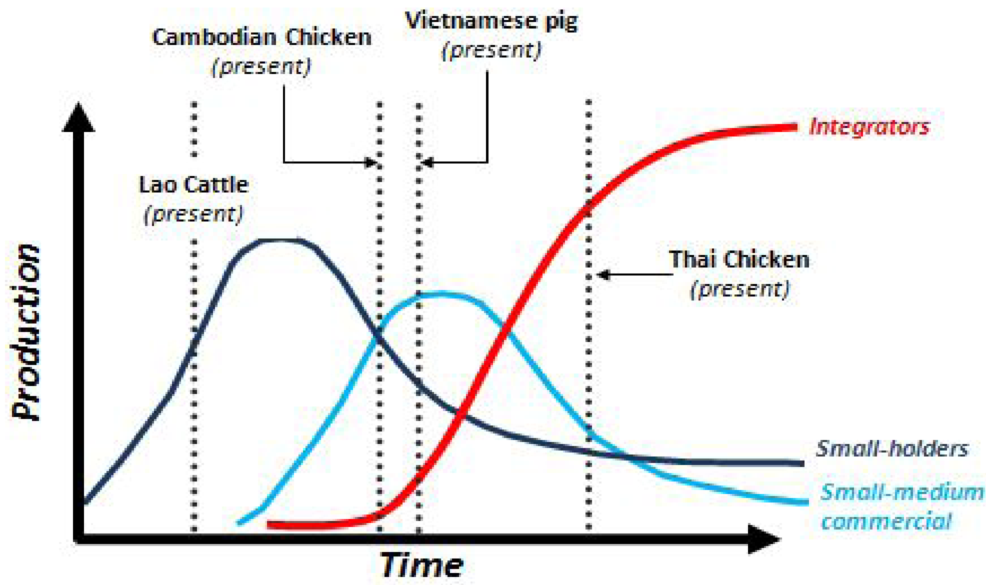
### 6.2.5 ENVIRONMENTAL CONCERNS

Increasing concern over local environmental degradation is an important factor governing policy and altering production methods. Vietnamese national and provincial policy in relation to the delta region provides a good example due to the particularly high population density and intensifying water quality issues. Agricultural policy and policymaking processes vary widely at subnational, national and regional levels but increasingly planning and screening tools and procedures are giving environmental concerns more weight, especially in the design and operation of intensive livelihood enterprises. Technocratic policy-informing and making channels are gaining strength across the LMB; however transparency and associated issues of "good governance" remain a challenge.

### 6.2.6 TRENDS AND VULNERABILITIES OF LMB LIVESTOCK SYSTEMS

Figure 6-2 shows trends in share of livestock production in the LMB by livestock system. Dashed lines show estimates of the current situation for specific national systems.

**Figure 6-2: Regional trends in livestock production over time**



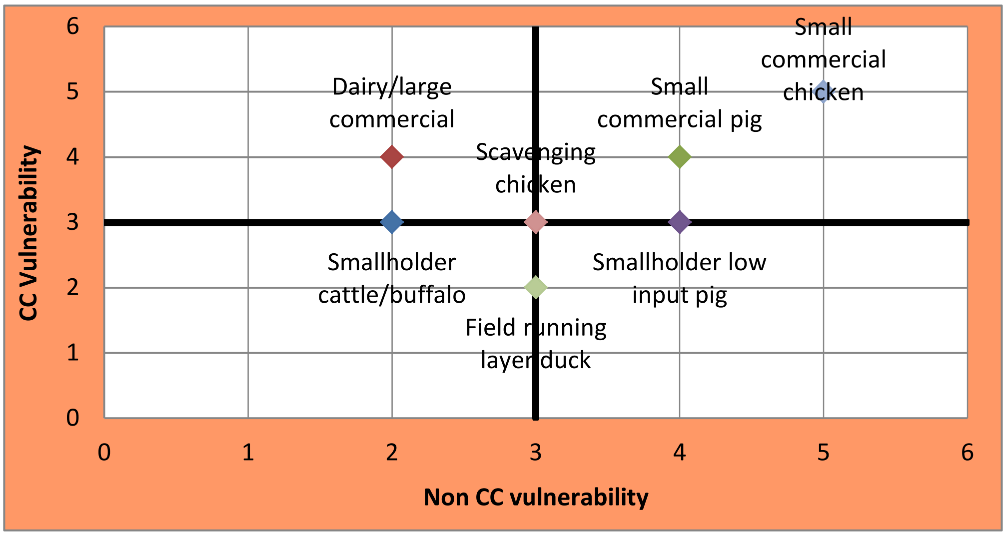

The overall rational for weighting of non-climate related vulnerabilities is presented in Table 39. Based on this weighting, Figure 6-3 depicts overall livestock system vulnerability to both climate change (y-axis) and non-climate related changes (x-axis) in the LMB. Small commercial chicken is shown to be the most vulnerable livestock system in the LMB to both climate and non-climate related factors. Climate change impacts will have relatively more effect on systems such as large commercial and smallholder cattle.

Expected trends in livestock systems in the identified hotspot provinces are provided in the detailed livestock theme report.

**Table 39: Non climate drivers of vulnerability of livestock systems**[47]

| Livestock System | Non-CC vulnerability | Summary rationale for non-CC vulnerability score | CC vulnerability |
|---|---|---|---|
| Smallholder cattle/buffalo | 2 | Limited competition in current and likely markets in the medium-term, vital to other household livelihood sources through integration with farming systems. | 3 |
| Dairy/large commercial | 2 | High capital investment, rapidly increasing demand, expected to continue rapid growth (from a low base). However, disease issues and long –term competitiveness are a possible future concern. | 4 |
| Small commercial pig | 4 | Increasing competition from large-scale more vertically integrated producers. Viability of these enterprises will be challenged by reduced margins. High stress systems, high vulnerability to disease and disease responses, limited capacity to invest further in husbandry. | 4 |
| Smallholder low input pig | 4 | Increasing competition from medium- and large-scale producers, less integrated with farming systems by comparison with bovines. Likely to remain popular in more remote areas in the short-term. | 3 |
| Small commercial chicken | 5 | Increasing competition from large-scale more vertically integrated producers. Viability of these enterprises will be challenged by reduced margins. High stress systems, high vulnerability to disease and disease responses, limited capacity to invest further in husbandry. | 5 |
| Scavenging chicken | 3 | Very low cost systems, significant consumer preference (though changing). Likely to remain prominent in rural and peri-urban areas in the short-medium term. | 3 |
| Field running layer duck | 3 | Very low cost systems, highly competitive with other production methods. Policy changes relating to disease control are not predictable but could change quickly. | 2 |

**Figure 6-3: Climate and non-climate vulnerability of livestock systems**




[47] Refer to climate change vulnerability assessments detailed in the Livestock Theme Report.

## 6.3 NATURAL SYSTEMS

Natural systems within and outside protected areas are under pressure throughout the Lower Mekong region. Generally, NTFPs and CWRs have greater resilience to climate change and other pressures in intact healthy forest and wetland ecosystems. However, very few of the forests or wetland ecosystems in the region can be considered intact. **The vulnerability of NTFPs and CWRs in stressed and modified natural environments is greater, and in these situations more rapid changes in the species and their ecology can be expected.** Ecosystems have tipping points where the extent of degradation leads to dramatic and often irreversible change—where the extent of forest loss, loss of the key species, and/or loss of soils leads to an overall transformation. Often this threshold is not obvious until the loss has occurred. Many parts of the LMB ecozones identified in this study have been irreversibly transformed.

**In the short term, non-climatic threats to LMB species and ecosystems are more serious in their impacts than climate change.** Habitat loss due to deforestation and changes in landuse to more extensive and intensive agriculture, plantations, and to aquaculture are very significant. Where natural habitats are still intact, over harvesting and destructive, non-sustainable, and illegal logging and collection are reducing forest area and quality and the populations of many NTFPs and CWRs. Increasingly, the collection of NTFPs is market driven, with high export values of some species pushing up the quantities collected and the numbers of people collecting. Climate change comes as an additional threat to already highly-stressed and degraded ecosystems.

### 6.3.1 FOREST AND HABITAT LOSS

**The main threat to NTFPs is the clearance of forests and changes in landuse for agriculture and agroforestry.** Over the past 50 years forest cover has changed dramatically in all LMB countries.

**In Lao PDR**, for example, the original natural forest cover was over 70% in the 1940s and by 2002 was reduced to 41.5% (Phongoudome et al. 2009). The UN REDD program estimates that, if the current reduction rate continues, the forest area will decrease to 7.4 million ha (31.3% of the total land) by 2020.[48] The main drivers of forest and habitat loss are shifting cultivation, legal and illegal logging, conversion to agriculture and forest plantations, and infrastructure development. Although secondary and recovering forests can be very productive sources of NTFPs, plantations for rubber and other monocultures lead to an almost sterile environment for most NTFPs. The national targets for agricultural land anticipate an increase from 1.2 million ha in 2002 to over 2 million ha by 2020.

**Thailand:** In 1961, forest covered over 51% of Thailand. Since then 11.5 million ha of forest has been lost, about 256,000 ha/yr. FAO (2009) estimated forest cover to be about 30.9% of land area in 2006 while the World Bank estimate was 37.14% in 2010.[49]

**Vietnam:** In the Mekong Delta, estimates for original forest cover range from 25% to 40%. Today the landscape has been transformed into a manmade agriculture landscape. Of the total land area of about 3.96 million ha, 2.6 million ha are being used for agriculture, mainly rice cultivation and aquaculture, accounting for 65% of the total land area—the remainder includes waterways, residential land, roads, and a small number of protected areas. The national plan to 2020 is to develop the Mekong Delta into a focal area for commercial agriculture and aquaculture production

[48] http://www.un-redd.org/AsiaPacific_LaoPDR/tabid/106705/Default.aspx
[49] World Bank, available at http://data.worldbank.org/indicator/.

with a high economic growth rate. The targets to 2020 are to maintain 1.8 million ha of rice, 0.5 million ha of aquaculture, and to increase the forest cover from the current 5% to 9%.[50]

### 6.3.2 OVER HARVESTING

**Over exploitation has led to significant reductions in some NTFP species**. This is a special concern where destructive harvesting is practiced it leads to progressive losses. In 2004, Foppes and Ketphanh highlighted changes in NTFPs, e.g., wildlife, fish, and rattan, based on village discussions in Lao PDR over the previous 10 years (Foppes and Ketphanh 2004). This study found that the increasing population using NTFPs, the intensification of harvesting, and increasing market prices were all acting to decrease NTFP availability. That trend has continued over the last decade. The scale and value of the illegal wildlife trade in the region is also a significant driver of decline in NTFP resources.

There has been successful domestication or cultivation of some NTFPs, e.g., false cardamom, mushrooms (especially those that grow on decaying wood), eagle wood plantations, bong bark plantations, growing of rattan shoots, and broom grass. False cardamom gardens have been established in southern Lao PDR, which are not plantations in the strict sense, but rather clearings in the forest where wild *Amomum* is allowed to regenerate after a year of growing upland rice (NAFRI et al. 2007).

Even if they can be cultivated, wild plants will still be collected. Orchids are now cultivated extensively, but there is still a high market for wild orchids that cannot be cultivated or are required for cross-breeding and for the perfume industry. These are removed from the forests throughout the region in very large quantities.

Some NTFP resources cannot be cultivated. If they are in demand because of their unique features, then populations will continue to decline. For example, the large, single-stemmed rattan species such as *Calamus poilanei* is very heavily harvested and declining throughout Lao PDR. It has effectively been eliminated in many former forest areas and protected areas in Cambodia.

In Vietnam, some wetland plants have been successfully domesticated and have become an important income for farmers. While *Typha* can still be found in the wild, it has been planted for commercial purposes. Farmers in Soc Trang, Bac Lieu, and Ca Mau provinces raise fish in their *Typha* fields yielding incomes of up to US$2,500/ha/yr. In low-lying areas, *Typha* has proven to be a more economically competitive crop than rice and it can be an important income source for farmers in acidic areas where rice gives low yield or where only one crop of rice per year is possible.

### 6.3.3 POOR PROTECTION MEASURES

Most of the NTFP and CWR species are not protected by law in any of the LMB countries. Even in protected areas, harvesting and collection by local people is usually permitted, and often large-scale collection activities are even allowed. Illegal collection is rarely controlled. The endangered status of many of the NTFP species has not been assessed in the IUCN Red List. Some species, especially trees, may have been assessed and have legal protection but this has not prevented exploitation.

For CWRs, exploitation is rarely the issue—they may even be considered weeds by surrounding populations. They tend to be neglected and forgotten. The loss of habitat is the key pressure, both of forests and wetlands. Since their importance lies in their genetic resources, and potential for

---

[50] Decision of the Prime Minister 939/QD-TTg dated on July 19, 2012 on approving the master plan for socio-economic development of the Mekong Delta to 2020.

cross breeding for disease and climate resistance, there is a risk of genetic erosion when wild stocks occur near fields cultivated with "improved" seeds. The risks of "weedy rice" are as dangerous to wild rice genetics as they are to the economics of cultivated rice in the fields.

In conclusion, *the existing pressures on natural systems and NTFPs are expected to continue, and the wild resources provided by the NTFPs will continue to decline*. The most important pressure is generally habitat loss and transformation, which reduces the natural populations and makes them more vulnerable to climate change. Over harvesting can be managed if the natural habitat remains, but in the absence of natural habitat the only option is cultivation and domestication of the NTFPs.

### 6.3.4 THREATS TO PROTECTED AREAS

The threats to protected areas in the LMB have been well-documented—and covered in this and other theme sections. In summary, they include the following:

**Population growth** makes protected areas even more crucial for the continued production of a range of marketed and non-marketed ecosystem-based goods and services. Based on current trends, and without strict development controls within the protected areas, continued population growth will further degrade these services.

**Infrastructure development,** such as dams and roads, has direct impacts and increases the accessibility of protected areas in the same manner as land concessions. They have cumulative and multiplier effects on natural systems both up and downstream of development. Expanding road networks that are poorly sited, designed, and managed are the category of infrastructure with the most serious impacts on protected areas in the LMB.

**Land concessions** – In Lao PDR and Cambodia there has been a surge of land concession grants within protected areas. A number of activities are associated with these developments, including commercial plantations, logging, hydropower, mining, livestock, tourism facilities, and building factories to process agricultural products. Land concessions are a major driver of forest loss and by providing access to previously inaccessible areas, introduce or intensify illegal logging and poaching in surrounding areas. Any form of land degradation resulting from land concessions within protected areas increases the vulnerability of ecosystems to climate change, and their capacity to adapt.

**Wildlife trading** in the LMB has national and international dimensions. The Mekong region is both a major supplier and major consumer of wildlife. Communities may harvest animals for food on an unsustainable basis. In most cases harvesting is driven by national and international markets. The demand for 'traditional medicines' is fueling a massive trade in rare and endangered animals such as the tiger, Javan rhino, and Asian elephants, as well as many plant species. Higher incomes in destination countries such as China increase demand for poaching, even as prices rise due to increasing scarcity.

**Agriculture expansion** – Agriculture is the chief source of rural income within the LMB. Population growth within subsistence-based communities and through immigration from resource-poor regions drives encroachment deeper into forested areas in search of arable land. Agriculture adjacent to forest areas also leads to incursion of invasive species into protected area ecosystems.

**Unsustainable logging** – Despite their legal status, protected areas in the LMB are the sites of vigorous logging activities. Most logging is illegal, though often facilitated by local officials; some is legally sanctioned, but unsustainable. At the household level, timber remains the principal fuel source for many communities, although this is not a driver of large-scale land clearing.

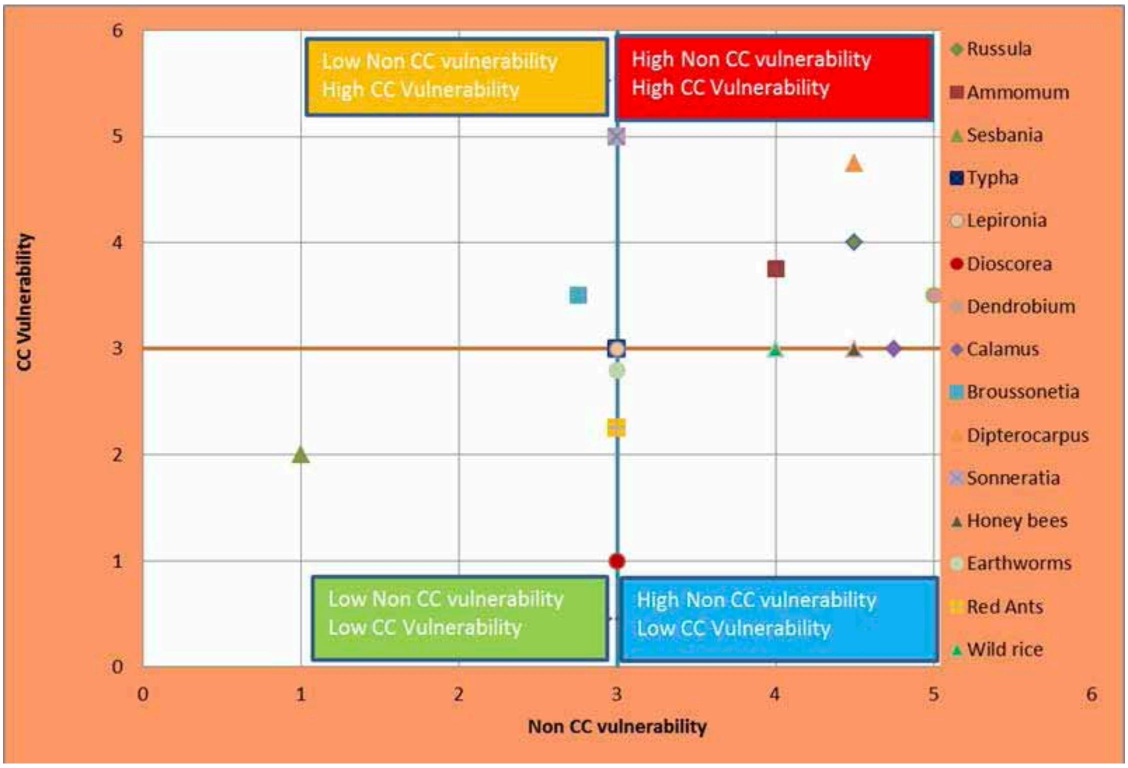
**Tourism** developments in the protected areas of the LMB are often under-resourced and inadequately managed, resulting in lost economic opportunities for local communities and the protected area and in damaging social and environmental impacts. Poorly-sited or harmful tourist facilities are a significant cause of degradation within protected areas.

### 6.3.5 CLIMATE CHANGE VERSUS NON-CLIMATE DRIVERS

The non-climate change and climate change vulnerabilities of the different species of NTFPs and CWRs within and outside protected areas have been aggregated for all hotspot areas and plotted on a chart in Figure 6-4. This shows that a significant proportion of the species considered fall into the quadrat reflecting high vulnerability for both non-climate and climate change-related drivers. This placement helps in determining the priority of actions for the different species across the basin. Thus:

- Species falling in the **bottom left quadrat (Low-Low)** – namely *Dioscorea* (climber) and *Sesbania* (aquatic plant)—probably do not require significant attention at the moment.
- Species falling in the **bottom right quadrat (High-Low)** – namely *Calamus* (rattan), red ants, honey bees, earthworms and wild rice (CWR)—need attention to protect the species and its habitat and encourage more sustainable harvesting, rather than specific climate change adaptation measures.
- Species falling in the **top left quadrat (Low-High)** – namely *Typha*, *Lepironia* (aquatic plants) and *Broussonetia* (shrub), require greater attention to climate change adaptation measures, although most of these species do have moderate non-CC vulnerability. Attention should be paid in the hotspot areas where these species are considered to be more at risk from climate change.
- Species falling into the **top right quadrat (High-High)** – namely *Sonneratia* (mangrove), *Dipterocarpus* (tree), *Amomum* (grass/herb), *Dendrobium* (orchid) and *Russula* (fungus)—need attention both to protection of the habitat, management for sustainable use **and** specific climate change adaptation measures, especially in those hotspot areas where they are considered to be most at risk from climate change.

Figure 6-4: Plot of non-climate change and climate change vulnerabilities for different NTFPs/CWRs aggregated for all hotspots




## 6.4 FISHERIES

**Over the next 10 or even 20 years, other factors threatening the future of LMB fisheries may completely overshadow the effects of climate change.** The productivity of the Mekong capture fisheries is inextricably bound up with the seasonal pulse of dry and wet seasons, and the connectivity of the rivers, streams, and floodplains. Developments that affect these characteristics will reduce productivity and biodiversity of the fishery, with secondary effects to the millions of people depending on the fishery for their livelihoods.

**The greatest threat to capture fisheries is the alteration of river morphology and hydrology caused by hydropower projects, the excavation of channels to aid navigation, and water extraction for irrigation**. Physical barriers constraining the migration of fish species can result in sudden failures of components of the fishery. Plans for cascades of dams, as proposed for Nam Ngum for example, could be catastrophic for this tributary's fisheries diversity and productivity. Periodically there are reports of plans to divert water from tributaries in Lao PDR or from the mainstream Mekong to the drier NE part of Thailand for irrigation purposes. In March 2013, Cambodia launched a US$200 million project to divert water from the Mekong River to irrigate 300,000 ha of rice fields in Prey Veng, Svay Rieng and Kampong Cham Provinces. If such projects come to fruition then their impact on the Mekong's capture fisheries would be considerable.

Other threats to the Mekong's capture fisheries include:

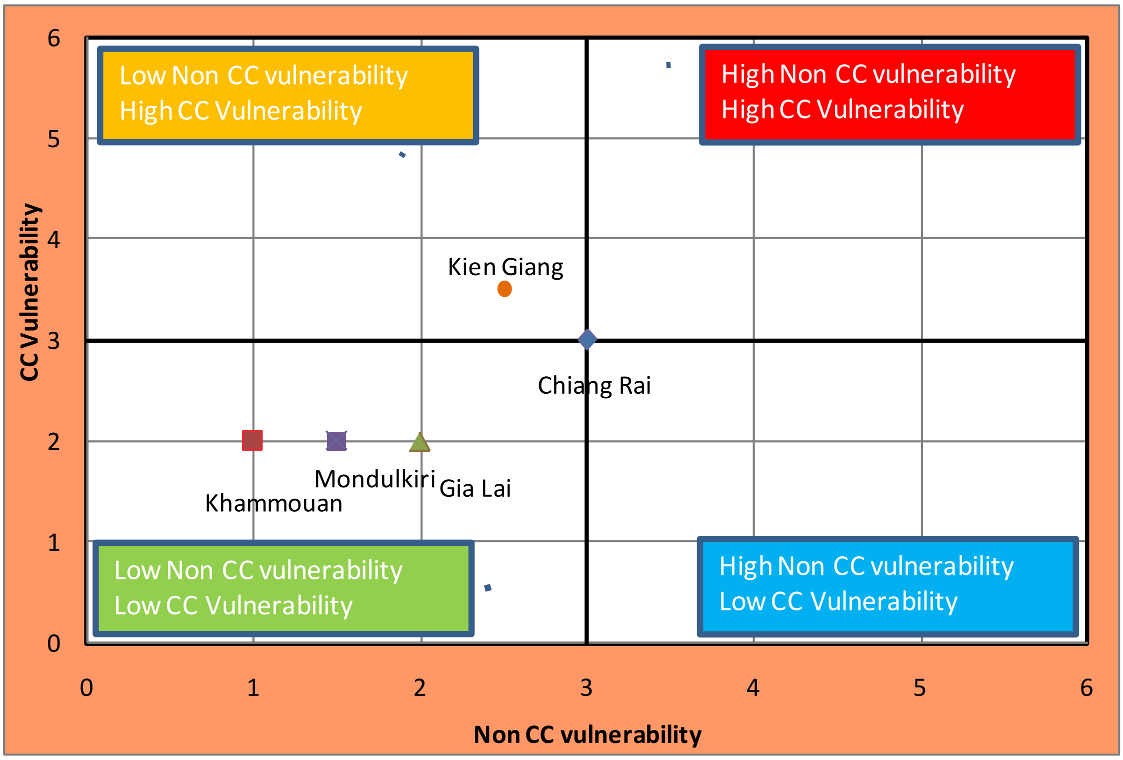
- Fragmentation of the river and floodplain fisheries and resultant loss of connectivity
- Loss of productivity through habitat destruction/change
- Overfishing, resulting from increased numbers of fishers and sizes of gears

- Aggressive fishing methods, e.g., explosives
- Radical changes in landuse patterns that change runoff patterns from upland areas
- Establishment of exotic fish populations from aquaculture escapees
- Water pollution from urban centers, industry, and intensive aquaculture
- Changes in water flows and levels through dam releases
- Climate change mitigation for other sectors e.g., large-scale irrigation projects

In recent years, there has been a tendency to blame unplanned and unwanted events in the region's capture fisheries on climate change, even when other causes seem more likely. Climate change is therefore becoming a scapegoat for shortcomings in more conventional development control and fisheries management. Consequently, climate change presents an opportunity to use vulnerability assessments and adaptation planning as a force for concerted and integrated management of LMB fisheries in ways that will address all threats.

Figure 6-5 provides an analysis of the aggregated non-climate change and climate change vulnerabilities of the key capture fisheries species for the primary hotspot provinces. For capture fisheries species, non-climate change vulnerability is less significant in the provinces of Khammouan, Mondulkiri, and Gia Lai than in Kien Giang and Chiang Rai.

**Figure 6-5: Plot of non-climate change and climate change vulnerabilities for capture fisheries in the primary hotspots**



## 6.5 AQUACULTURE

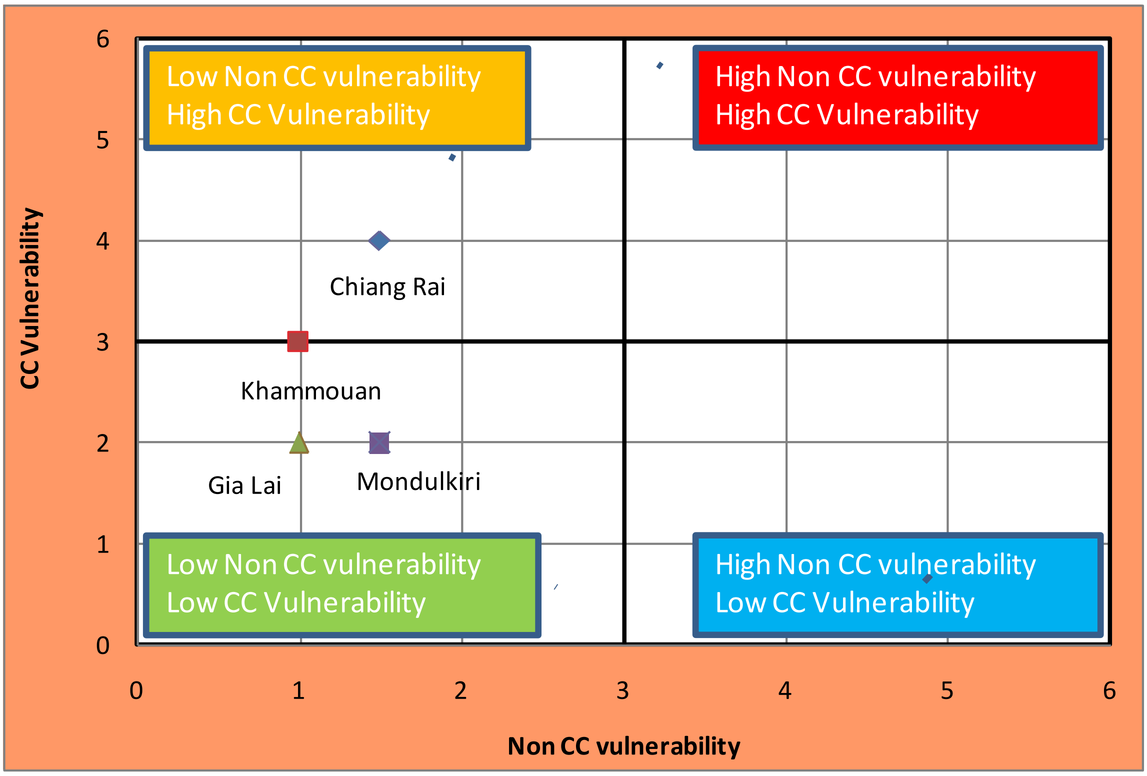
**There are far fewer external threats to the Mekong's aquaculture systems than those facing the capture fisheries.** For several decades, the trend has been stable capture fisheries production but exponential cultured fish production. Aquaculture is seen as a way to offset declining capture fisheries. However there are a number of non-climate change related pressures on aquaculture systems including:

- Competition from agriculture and other users for freshwater in the dry season
- Increased use of pesticides and drugs (in the more intensive aquaculture systems)
- The emergence of new diseases, such as Early Mortality Syndrome in white shrimp
- Pollution of freshwater and coastal waters, especially during the dry season

Pollution and increasing demand for water during the dry season has the potential to constrain aquaculture development, particularly in the Mekong Delta. Adaptation efforts in other climate-affected sectors that reduce the availability of water for aquaculture could be a serious check to further growth. This may be offset by an increase in dry season water flows resulting from dam developments in the Mekong and its tributaries.

Figure 6-6 provides an analysis of the aggregated non-climate change and climate change vulnerabilities of the key aquaculture species for the primary hotspot provinces. Three of the hotspots fall into the low non-climate change and low climate change vulnerability quadrat. Chiang Rai and Khammouan fall in the low non-climate change and high climate change vulnerability quadrat meaning that climate change impacts will be a more important consideration in these provinces.

**Figure 6-6: Plot of non-climate change and climate change vulnerabilities for aquaculture in the primary hotspots**



## 6.6 SOCIO-ECONOMICS (HEALTH AND INFRASTRUCTURE)

The LMB region is experiencing rapid economic growth. This began first with Thailand, followed by Vietnam during the 2000s, and more recently Lao PDR and Cambodia. *In coming decades, economic expansion at current rates of 6% to 10% per year will generate a larger pool of financial resources to dedicate to adaptation.*

With regard to rural health and infrastructure, projected economic growth will finance beneficial public and private-sector spending, such as: (i) investment in critical social services, such as health services, education, and access to safe drinking water and sanitation; (ii) extension and strengthening of rural infrastructure networks, particularly roads; and (iii) expansion of access to rural credit. If well-planned and managed, such investments will reduce the vulnerability of rural communities to climate change. Broader development of markets will also strengthen the rural health and infrastructure sectors, e.g., greater employment in the formal sector and access to markets driving higher incomes, and access to infrastructure associated with major development projects (such as dam access roads).

An efficient response to climate change does however require more than extra financial capital, the physical capital it purchases, and greater economic activity. Governments must consider the future state of natural capital (e.g., forests, wetlands, and uplands) that is rapidly deteriorating under the LMB's current development trajectory. In many areas climate change could degrade this natural capital even further. The stronger the base state of natural systems before climate-induced shifts are fully realized, the lower the vulnerability and the less adaptation that will be required.

When considering rural health and infrastructure in this study a range of criteria were used to assess livelihood vulnerability to climate change (i.e., poverty, food security, demographic composition, strength of key infrastructure, and human health); as well as to assess its adaptive capacity (i.e., physical assets, education/skills, physical infrastructure, and access to markets). Any of these criteria are inextricably linked to the ability to access functioning ecosystems and the services they provide. In the LMB that dependency will persist for many decades. For infrastructure, the regulation of extreme monsoonal precipitation by forests and watersheds, for example, is critical. In some areas climate change poses a threat to these ecosystem services; in many areas current development trends are a more serious immediate threat to these same services.

In this section several major non-climate factors that affect adaptation planning are considered in terms of: (i) their impact on rural health and infrastructure provision, and (ii) their environmental impacts that, in turn, affect vulnerability and adaptive capacity. Each of these non-climate change drivers of change are raised as key issues by other theme groups in the study—here their social and economic implications are considered in these narrower contexts.

This section ends with a summary of other developments by hotspot province and accompanying diagrams. The quadrant diagrams present the climate change vulnerability of the health and infrastructure sectors in each hotspot province, the vulnerability by province of these sectors to shifts in the non-climate change factors, and a comparison of provinces by sector.

### 6.6.1 HYDROPOWER DEVELOPMENT

Hydropower dams are associated with a range of environmental risks: from altered downstream water regimes to reductions in fisheries and loss of downstream sediment transfer. Subsistence based communities in the vicinity of dams may be subject to rising poverty and food insecurity due to: (i) loss of capture fisheries and riverside agriculture, (ii) inundated farmland in upstream areas,

(iii) reduced sediment transfer to downstream floodplain causing lower agricultural productivity, and (iv) forced relocation to less fertile land.

Although there are substantial environmental and social risks associated with dams, their development may also be associated with improvements. In the infrastructure sector, dam access roads may provide surrounding communities with improved access to markets. Dams may also provide flood control benefits. Resettlement programs may improve health access, and stronger communal and household buildings, as well as access to electricity (for example, NTPC 2008).

In the long term, it may be that government revenue and other broad benefits of hydropower development trickle down to affected communities. But the overriding experience of the LMB is that in the direct, short and medium term hydropower dams will increase local poverty and food insecurity, and thereby represent a threat to rural health. For infrastructure, the outcome is less discernible because there is significant capacity for dams to increase access to improved and more abundant infrastructure resources, particularly roads.

### 6.6.2 LAND CONCESSIONS

A range of activities are associated with expanding concessions, including plantations, logging, hydropower, mining, intensive livestock, and building factories to process agricultural products. These projects often involve: (i) displacement of communities without formal land tenure, (ii) reduced access to natural resources for communities adjacent to new land concessions, and (iii) degradation or removal of ecosystem services previously located in land concessions. In the absence of strong social and environmental protection and regulation, land concessions have become major drivers of landlessness and poverty.

### 6.6.3 DEFORESTATION, ILLEGAL LOGGING, POACHING

Land concessions are a major driver of forest loss and, by providing access to previously inaccessible areas, introduce or intensify illegal logging and poaching in surrounding areas. However, the degradation of forest resources is a much broader issue than land concessions. The negative impacts on community health of loss of natural forest resources were assessed earlier. Less visible, but just as important for community health, is the role of watershed protection in soil water retention and the mitigation of flood events. Those last factors are highly relevant to infrastructure resilience, but also health in terms of asset loss and crop destruction from flood events, landslides, and land degradation.

### 6.6.4 POPULATION GROWTH AND MIGRATION

Regional population growth is increasing pressure on natural systems and the services they provide in rural areas. There has been a growing trend in rural-rural migration to access remaining forest areas, leading to conversion to agricultural land. On current trends, continued population growth would see a further degradation of natural resources and reduced climate change resilience in rural communities. That forecast is balanced somewhat by rising rural-urban migration; all countries in the LMB except for Cambodia are projected to have declining rural population by 2025.

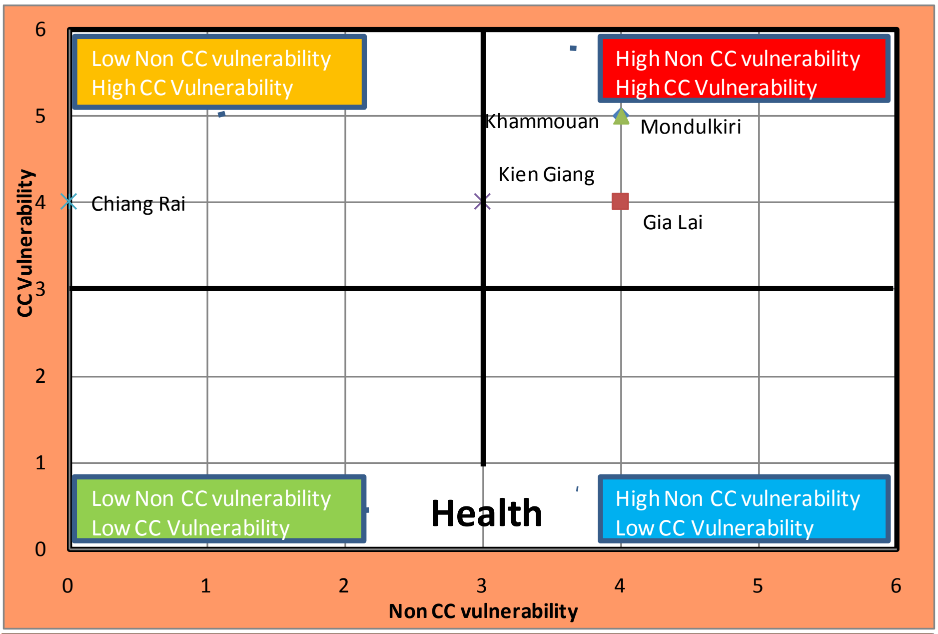
Whether the shift of large numbers of people out of rural areas necessarily improves access to natural resources for those remaining is an open question: subsistence farming may be replaced by larger economic concessions that have a bigger natural systems footprint than existing rural communities. Another important question is whether rural-urban migrants are able to access social services, training, housing, and, more generally, livelihood support once they have relocated to cities;

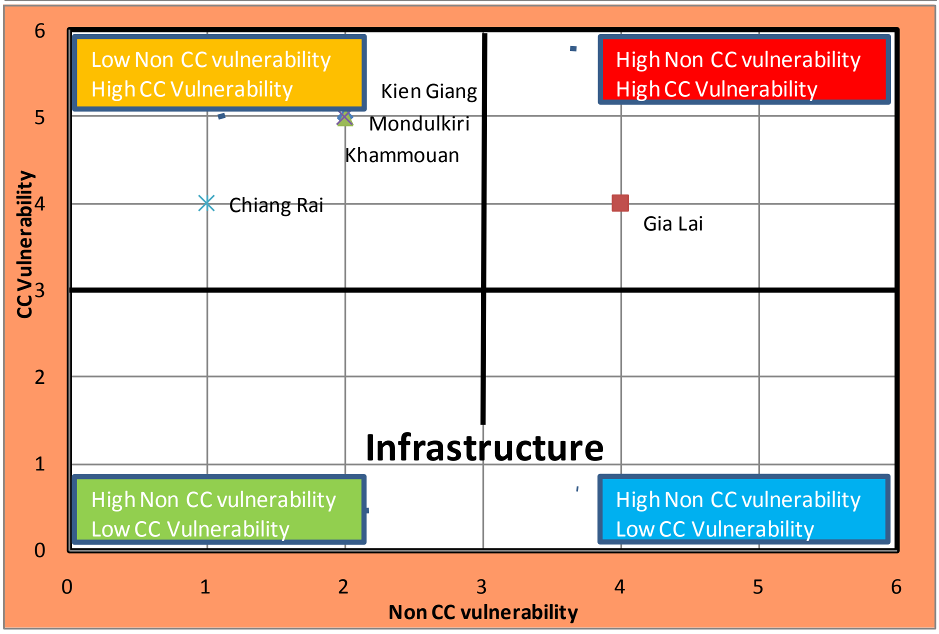
an important element of rural-based adaptation may therefore be preparing households to make this transition and ensuring that their welfare actually does improve.

## 6.7 SUMMARY OF OTHER DEVELOPMENT IMPACTS ON SECTORAL VULNERABILITY

Figures 6-7 (a) and (b) summarize the aggregate non-climate change and other development-related impacts on the vulnerability of the health and infrastructure sectors across all hotspot provinces. The multiple charts associated with Figure 6-8 summarize the health and infrastructure vulnerability to climate change and other development threats for each hotspot province.

**Figure 6-7: Summary of (a) health and (b) infrastructure vulnerability to climate change and other development threats**



### 6.7.1 OVERVIEW

#### 6.7.1.1 Chiang Rai

No additional hydropower is anticipated in the province, however there are major dams being built on the Mekong mainstream in China. Reforestation activities are taking place in the province and protected areas under relatively strong protection (compared to the rest of the LMB). Population is stable and, if anything, declining slightly.

*Aggregated threat ranking:*

- *Health, Very Low;*
- *Infrastructure, Very Low.*

#### 6.7.1.2 Gia Lai

There are large numbers of existing hydropower plants in this province (e.g., Yali Falls and other dams on Sesan cascade) with more planned. Hydropower has had a negative impact on downstream areas in terms of food security. Dam-induced floods and droughts have been reported. Population is growing due to inward migration; this is also displacing minority groups to marginal land and driving degradation of existing agricultural land in sloping areas.

*Aggregated threat ranking:*

- *Health, High;*
- *Infrastructure, High.*

#### 6.7.1.3 Khammouan

Several large hydropower plants are already in operation in the province (e.g., Theun-Hinboun and Nam Theun 2) with further planned. Resettled villages from Nam Theun 2 have reportedly experienced substantial improvements in health and infrastructure access. Mining projects are also reportedly improving road access. Deforestation and other harmful forest activities are common, as is the granting of land concessions. Population is growing. Electricity access has risen in recent years.

*Aggregated threat ranking:*

- *Health, High;*
- *Infrastructure, Low.*

#### 6.7.1.4 Kien Giang

Planned Mekong mainstream hydropower would have a major impact on sediment discharge in delta areas, reducing agricultural and fish productivity. The population is growing but migration to Ho Chi Minh is likely to increase in line with other areas of the Mekong Delta. Economic development in the province is expanding rapidly. This development increases economic activity but also places further strain on remaining natural resources. The major infrastructure in the province is the irrigation network, parts of which are in the process of being upgraded to respond to climate change.

*Aggregated threat ranking:*

- *Health, Medium;*
- *Infrastructure, Low.*

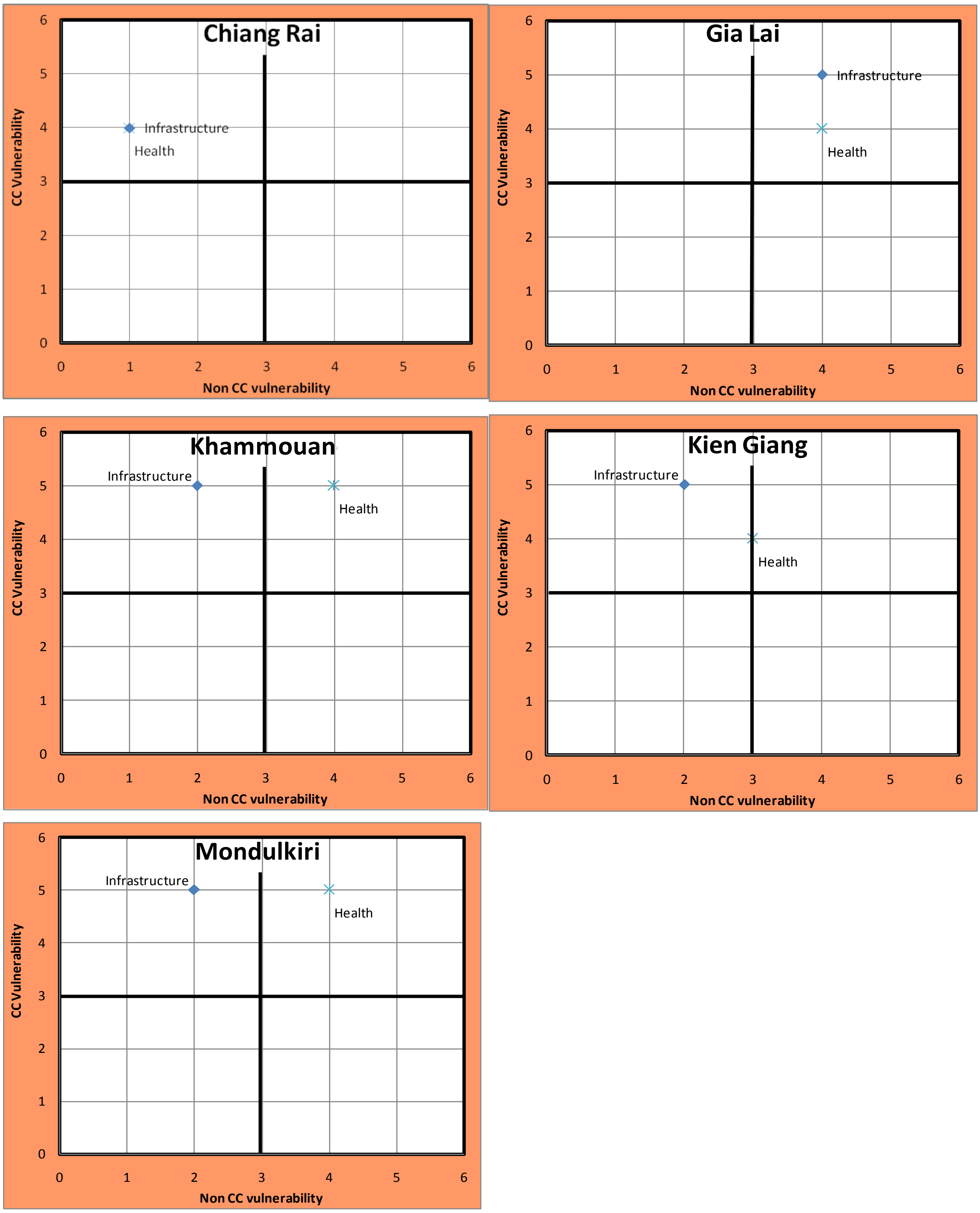
#### 6.7.1.5 Mondulkiri

Significant hydropower on the Sesan River (on the border of Mondulkiri and Ratanakiri Provinces) upstream in Vietnam with large dams also planned or approved in Cambodia. Vietnamese dams have had a strong negative effect on food security and poverty in downstream areas of the Sesan, culminating in forced migration. Although protected areas encompass a large portion of the province's area, economic land concessions for agriculture and mining are also widespread and have been the cause of community displacement. However, these projects are increasing the quality of road and electricity access in remote areas. Deforestation, land-clearing, and other illegal activities are rapidly reducing community access to forest resources. Population is growing rapidly (from a low base), with migration from other provinces towards remaining natural resources.

*Aggregated threat ranking:*

- *Health, High;*
- *Infrastructure, Low.*

**Figure 6-8: Summary of health and infrastructure vulnerability to climate change and other development threats in primary hotspot provinces**



## 6.8 CROSS-SECTOR IMPLICATIONS

From a cross-sector perspective, the primary challenge posed by forces affecting agriculture, livestock, fisheries, and natural systems such as major infrastructure developments and land concessions is that they have multiplier and cumulative effects. For example, roads to service hydropower projects open up previously inaccessible areas to logging and plantations. Mining and timber concessions lead to processing facilities that cause water and land pollution. In the absence of integrated area-wide planning and coordination, market-driven developments are likely to have a mounting impact on the natural systems foundations for rural livelihoods in the LMB.

As stressed throughout this report, *the diverse components of rural livelihood systems are all dependent on healthy functioning natural systems.* Climate change may not be the main source of decline, but its marginal impact is greater if it is placing further stress on highly-stressed systems. Major developments are reducing resilience in rural livelihood systems. For example, food security in certain areas is being undermined by dams and altered flow regimes degrading downstream riverside agriculture. There will also be reductions in rice yields due to climate change. Where such a combination of current and projected threats coincides, then it may be that climate change applies terminal stress to the viability of already weakened systems.

# 7 ADAPTATION

This study set out to identify geographic areas of the LMB most affected by projected climate change. As a framework for that analysis, the study divided the LMB into 12 ecozones, five livelihood zones (which are an aggregate of the ecozones), 104 catchments, and 114 protected areas. The aim was to establish a common analytical foundation for viewing livelihoods and farming systems from an ecological perspective. The spatial framework also included the 88 provinces in the LMB—an important layer added for very practical reasons because it is the main local government level responsible for planning and managing development, for gathering information, and for tracking progress. It will be the critical level for adaptation replication and mainstreaming.

Within that spatial framework, the study assessed the impacts of climate and hydrological changes on agriculture, capture fisheries and aquaculture, livestock, natural systems, and on rural health and infrastructure. In each of those sectors, the modeling, assessment, and adaptation planning dealt with individual species and systems. The scientific basis for the analysis drew from research that has been conducted at species level. The analysis of systems built on those species assessments but, as so little is known about how farming and natural systems function, it depended largely on past experience and expert knowledge and judgments. Similarly, the development and assessment of adaptation options for vulnerable species and systems and their distillation into strategic adaptation priorities was guided by past field experience – summarized here as a set of principles.



## 7.1 ADAPTATION GUIDING PRINCIPLES

Experience of communities and governments in the region in responding to past extremes, climate variability, and climate change suggest a number of principles set out here that should guide adaptation planning and action.[51]

**Recognize the fundamental role of natural systems in maintaining and enhancing resilience:** Recognize that healthy natural systems are a foundation for the development and well-being of socio-economic systems and are essential in building resilience in communities, economic sectors, and areas. Adaptation actions should always contribute to ecological sustainability and social equity as well as to reducing climate change vulnerability; the corollary to that axiom is as important—to ensure that adaptations do not contribute to environmental and biodiversity degradation.

**Weed out bad adaptation:** Existing development plans and budgets—and adaptation options—need to be filtered through an *adaptation impact assessment* process to ensure those actions: (i) do not have a negative impact on the adaptation options and capacities of other sectors, (ii) do not rule out future adaptation options and stages, and (iii) do not degrade natural systems that lay the foundation for resilience to climate change.

**Recognize the cyclical and iterative nature of adaptation:** There is no permanent "fix" to climate vulnerability. Adaptation responses need to be regularly adjusted based on experience and

[51] Based on ICEM, 2012, *Basin-Wide Climate Change Impact and Vulnerability Assessment for Wetlands of the Lower Mekong Basin for Adaptation Planning: Synthesis paper on adaptation of Mekong wetlands to climate change*, Prepared for the Mekong River Commission by ICEM in partnership with IUCN, World Fish and SEA Start. Hanoi, Viet Nam.

new information. It is not necessary or possible to do everything at once—priorities need to be set with less urgent measures left to later development cycles. Some things need to be done before others are possible. Climate change is incremental and so too is adaptation.

**Adapt on a phased basis:** Adaptation is best achieved in phases. Adaptation planners need to monitor, learn lessons, and make adjustments over time—new approaches or adjustments to plans may be needed as more climate change information comes to hand. One phase should provide a good foundation for the next. The most important things need to be done first. Also, economic feasibility may be a driver for adaptation phasing. Some adaptations such as raising river embankments or dyke systems may be needed but are just not possible now for economic reasons. It may be necessary to accept a "repair as needed" approach as assets are degraded or destroyed by floods and storms, rather than constructing now to meet future extreme conditions. The economic, social, and environment implications of delaying action should be understood.



**Integrate adaptation with development planning:** Recognize adaptation actions as part of management and development planning cycles so they become an integral part of sector socio-economic plans, budget allocation, and staffing commitments. Climate change impact, vulnerability, and adaptation assessments need to lock into sector and area planning steps. Integration with existing planning encourages assessment of non-climate stresses which degrade and weaken the resilience of wetlands and other natural systems. Avoiding or reducing non-climate stresses is a critical ingredient in adaptation plans.

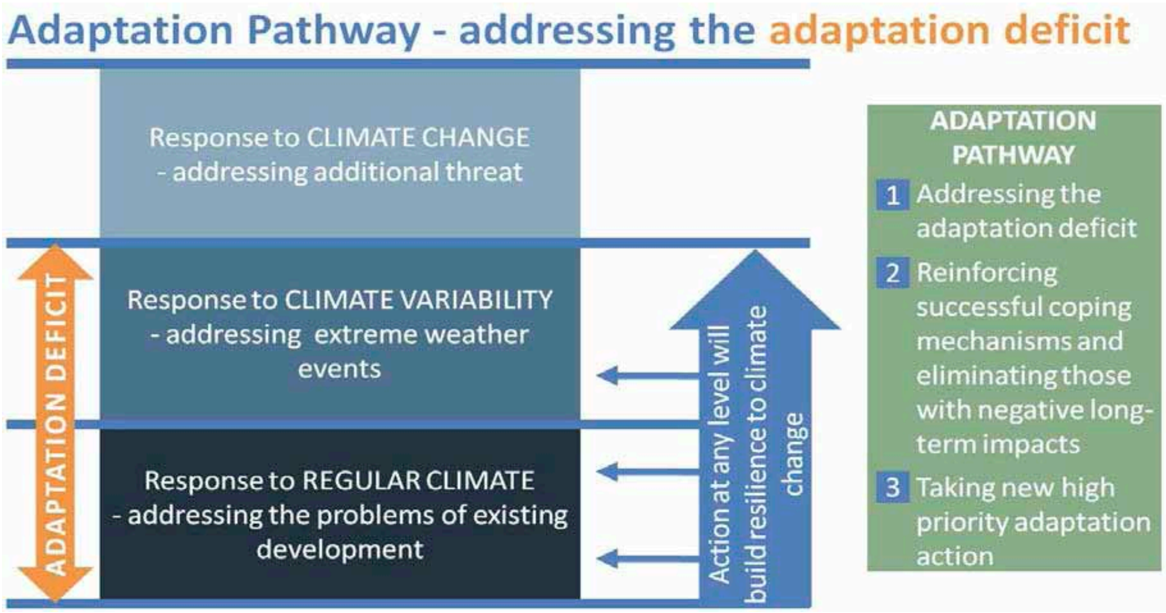
**Involve local communities and government:** In most cases, the science evidence base concerning the biology and ecology of species and habitats is limited. Local communities and managers have site- and species-specific knowledge built up over generations. Vulnerability assessments and adaptation planning need to respect and rely on local experience, knowledge, and judgments. Natural system users and local communities, local government, and sector specialists need to be involved in all phases of the adaptation cycle—defining the threats, assessing the impacts, identifying adaptation options and priorities, implementing adaptation, and monitoring and adjustment.

**Address the adaptation deficit first** (Figure 7-1): The adaptation deficit includes those things which government or communities need to do to safeguard their assets against existing climate extremes and variability, in the light of past experience. Those actions may also be priorities for meeting basic developing needs. Addressing many day to day environmental, development, and maintenance challenges can enhance resilience to storms and floods, for example, of the kind already experienced—and to more extreme future conditions due to climate change.

If the first steps in adaptation planning and implementation are focused on the adaptation deficit, it brings climate change to the immediate agenda and budgets of local planners in ways they appreciate and understand and that meet existing development needs.

**Figure 7-1: Addressing the adaptation deficit**

*Source: ICEM 2011*




**Build on an understanding of past extremes and trends:** Stakeholder experience, official records, and expert judgment should all be consulted. In many cases limited available information and capacities do not allow for reliable science-based projections. As an initial planning response, it may be necessary to understand and document local experiences with past extreme events such as floods and droughts and, if adequate records are available, to project forward past trends. Documenting the past may involve community surveys and mapping past floods and storm impacts from community memory.

**Build on past successful adaptation:** The best of what is already in place needs to be documented as part of an "adaptation audit" and replicated. In responding to past extremes in climate—e.g., storms and floods—government sectors and communities have often taken rehabilitation actions and made innovations to infrastructure design and resource management which "storm proof" their assets. They may have built those innovations into current and future sector work programs and budgets. Adaptation plans need to learn from and build on that innovation whenever it appears in sector plans or is demonstrated successfully in local areas.

**Focus on integration across sectors and areas:** Adaptation action is best implemented by integrating actions across systems, sectors, and geographic areas. Opportunities for reducing vulnerability through adaptation can be found in natural, built, social, economic, and institutional systems, for example:

(i) Natural systems adaptation (e.g., rehabilitation, revegetation, species/ecological enrichment, elimination of exotics, conservation offsets, and corridors)

(ii) Engineering solutions (e.g., dykes, drainage systems, bank stabilization, and other bioengineering options)

(iii) Landuse planning (e.g., zoning, safeguards and development controls, and management plans)

(iv) Traditional local strategies (e.g., seasonal restrictions on harvesting and conservation zones)

(v) Community and social adaptation (including resettlement, retraining, awareness outreach, and extension services)
(vi) Economic instruments (e.g., subsidies, fees and tax incentives, and payments for ecosystem services)
(vii) Sector-specific adaptation practices (e.g., fisheries—controls on equipment and quotas, agroforestry, ecological and organic approaches to agriculture)
(viii) Policies and plans (e.g., integration of adaptation into wetland management plans through to national policies on wetlands and their sustainable use)
(ix) Institutional mechanisms and structures (e.g., establishment of management boards, community management committees, and introduction of adaptation impact assessment procedures)

In most cases, an effective response requires an integrated set of adaptation actions across those fields of management so that one reinforces the other.

**Address the gender and ethnicity gaps:** A first step to addressing the adaptation deficit is targeting the gap in opportunities available to women and ethnic minority groups compared to the rest of the rural population. Participation is key: these groups need to be engaged at the household level from the vulnerability assessment stage through to the implementation of adaptation. It not possible to generalize what the specific impacts of climate change will be on vulnerable groups in a specific community. Thorough and original consideration of the socio-cultural context is necessary in each case. Systems and processes have already been developed for this purpose, such as those contained in CGIAR/FAO (2010) and UNDP (2010).

There may be trade-offs between different sectors associated with specific adaptation policies. Similarly, there may be trade-offs present between raising the adaptive capacity of one group within a community or household at the expense of others. Once again, these issues can only be understood through detailed field-level analysis. Where present, however, the welfare of vulnerable groups needs to be given priority.

## 7.2 AGRICULTURE

Adaptation responses are proposed for the most vulnerable agricultural commodities for each provincial hotspot. Suggestions are made to build the resilience of farming systems. They are presented as generic strategies and not detailed plans—those need to be developed in a site- and system-specific way. Before developing techniques for on-farm trials, a precise and detailed diagnostic of the farming system is required, as is an evaluation of the needs and capacity of the targeted communities in order to fine-tune adaptation options. Past experience and interventions in the targeted community have to be assessed as well to understand underlying drivers of success and failure.

The study team has distilled climate change adaptation in agriculture in the LMB into four strategies that aim to improve the resilience of small-scale producers in subsistence and industrial crops. The main orientations are:

(i) *Strengthening resilience in rainfed and irrigated rice-based systems with improved varieties, better management practices, and protective measures against extreme events.* This strategy includes the use of varieties that are early maturing to avoid flooding, that are flood tolerant, or that are drought resistant in drought-prone areas. The positive lessons from application of the "System of Rice Intensification" (SRI) techniques (which are discussed in more detail below) should be built into the cropping system.

(ii) *Improving water efficiency and water management techniques* (water harvesting, small–scale irrigation, etc.) in drought-prone areas to alleviate rain shortages that cause crop failure.

(iii) *Improving soil fertility and soil management* of both cash and subsistence systems in plains, plateaus, and uplands.

(iv) *Promoting agriculture diversification to reduce reliance on monoculture.*

### 7.2.1 ADAPTATION FOR RICE-BASED SYSTEMS

**Rice-based systems will require the development of new varieties for tolerance and adaptive capacity to higher temperatures, flood, and dry spells:** For example, new flood-tolerant and submergence-tolerant rice varieties[52] ("Scuba rice") developed by IRRI are now available and can help reduce flood impacts.

**Diversity in varieties:** To address the uncertainty of drought, flood, and rainfall patterns, farmers in Kandal Province, Cambodia already build resilience by planting a diversity of rice varieties of different maturation periods within their plots.

**Heat-tolerant varieties:** These will be required for rainfed rice in Kampong Thom, Mondulkiri, Khammouan, Champasack, Sakon Nakhon, and Chiang Rai and for irrigated rice in Kampong Thom, Champasack and Kien Giang. In some cases, for example, Kien Giang Province, a shift of the cropping calendar to avoid the peak heat period will be sufficient to limit the temperature stress.

**Drought-tolerant varieties**: In Cambodia and northeast Thailand[53] drought-tolerant varieties to reduce the risk of dry spells will be required. Early maturing crops, and/or submergence-tolerant varieties can be used in Kampong Thom, Kien Giang, Mondulkiri, Khammouan, Champasack, Chiang Rai, and Sakon Nakhon in flood-prone areas.

**Market availability and extension:** The shift to tolerant seed varieties depends on their availability on the market. Drought-tolerant, early-maturing varieties and submergence-tolerant varieties are available but need to be introduced to communities. Heat-tolerant varieties can be introduced later when the increase of temperature will be more significant.

To reduce vulnerability to extreme events and increase water efficiency, SRI offers promising adaptation methods for rice-based systems. SRI is a widely applied technique of cultivating rice that aims to improve rice yield while reducing inputs. The technique is based on several principles (i.e., significantly reducing plant population, improving soil conditions and irrigation methods for root and plant development, and improving plant establishment methods)[54] and farmers can chose to apply the entire process or to select only some steps according to their capacity and local conditions. The technique can be applied in irrigated and rainfed systems but requires improved water management capacity.

In the context of climate change, SRI can be an adaptation measure for:

- Reducing the impact of increases in temperature on rice yield
- Reducing demand for water

[52] http://www.irri.org/index.php?option=com_k2&view=item&id=9148:climate-ready-rice&lang=en

[53] Even if climate modeling predicts an overall increase of rainfall during the monsoon, risk of dry spell during the rainy season in northern Thailand will still be high and remains a major concern for farmers

[54] http://sri.ciifad.cornell.edu/

- Lessening the impacts from climatic events such as drought, flood, and storms with more robust rice plants, and
- Reducing the use of nitrogen fertilizer and reducing GHG emissions (in the case of water management capacity at the plot level) (Africare 2010)

This approach is recommended in most of the hotspots. It will be especially important to test or expand SRI in hotspots under high threats of extreme climate events such as storms and flash floods in the Vietnamese Central Highlands and Lao PDR. In those areas, the development of more resilient rice farming systems using SRI techniques will be an essential adaptation strategy. This adaptation can be planned and delivered in a short period, with thousands of farmers in the region already adopting elements of SRI. Other alternative rice production techniques such as alternate wetting and drying or cultivation of aerobic (non-flooded) rice can help to reduce water consumption from rice culture.



#### 7.2.1.1 Rice-based systems in coastal zones

Rice-based systems in the coastal zones will require additional infrastructure to face sea level rise, storms, and saline water intrusion. Dykes and other engineering structures have been shown to have negative effects on productivity after initial increases due to losses in soil fertility and the need for increased chemical inputs. Consequently, bioengineering approaches building on traditional methods should be widely applied in ways where local communities can be more involved in design and maintenance.

Saline-tolerant and short-growth duration rice varieties with high yields and good-grain quality will be a longer-term adaptation approach. Also, a shift to a rice-shrimp system will be required in areas where saline water intrusion will constrain a second rice crop.

#### 7.2.1.2 Shift to irrigated rice and fish culture

In flood-prone areas like Khammouan, Kampong Thom and the Cambodian floodplain, rainy season rice crops will be vulnerable. In those areas, a shift to a dry season crop and recession rice will be required if feasible in the new conditions. Also, with the development of small-scale irrigation, integration of fish culture is an option to be tested to diversify income and for nutritional benefit at the household level. In flooded rice fields, dry season fish refuge ponds managed by communities can support a productive rice field fisheries sector. Individual farm fish culture in flooded rice fields is an option in the Mekong Delta where the amplitude and duration of the flood will become more intense.

### 7.2.2 IMPROVEMENT OF WATER USE TECHNIQUES

**Access to irrigation with groundwater, rainwater collection, and small-scale water storage can provide opportunities for dry season crops**, supplementary irrigation, or diversification with homestead-intensive gardening. This diversification strategy in areas that are well-connected to markets can provide a new source of income while building resilience and stability in the farming system.

**Water storage or efficient water use techniques, such as low cost drip irrigation, mini-ponds, and rainwater harvesting in ponds or tanks,** are options already tested that can help to diversify agriculture production and secure rainfed crops. Those techniques can be developed across the hotspots, but vegetable and horticulture production requires a good connection to the markets. Areas without access to irrigation or have other water access issues need to consider rainwater harvesting technologies. For the poorest and especially landless, rainwater harvesting associated with drip irrigation in homestead gardens is a potential option to diversify income.

Additionally, this adaptation strategy can target women, with homestead garden vegetable production and marketing activities. Vegetable production can be oriented to specific niche markets, for example, where there is growing demand for organic products around city centers and tourist areas. Improved water efficiency and water saving techniques in rice culture can be achieved through SRI approaches, alternate wetting and drying and cultivation of aerobic rice.

### 7.2.3 SOIL MANAGEMENT AND FERTILITY

**Some of the negative impacts of climate change can be mitigated through better fertility management at the plot level.** Yield gap is important and both fertility management and the use of fertilizer are partially responsible for this gap. Yields of the main crops show large variations across the LMB.

One option to reverse the loss of fertility in commercial agriculture (e.g., for soya, maize, and cassava) is to develop a cropping system that includes the rotation of crops with permanent vegetal cover, and limiting or abandoning tillage to improve the quality of soil organic matter and to promote nutrient availability. This system is flexible and can include the integration of pasture land in plains and of local traditional crops[55] in rotation with grains and/or forages to stabilize and diversify the production system. Also this approach can be combined with rice-based systems particularly in medium- to large-scale farms.

In addition, continuous vegetal cover is an option for uplands requiring specific soil conservation techniques in response to extreme rainfall events and storms. Additional adaptation measures for protection against flash floods will be required in uplands area, emphasizing bioengineering methods with tree plantation and physical barriers.

These soil conservation-focused adaptation options would apply in several hotspots facing erosion due to extreme rainfall events (e.g., Khammouan, Gia Lai, Mondulikri, and Champasack) and in hotspots where agriculture is now oriented toward commercial crops such as cassava, soya, and maize and use larger quantities of chemical inputs (e.g., northeast Thailand, western Cambodia and the Mekong corridor in Lao PDR). The general approach can be tested and introduced in a short period, since the techniques and technology are already commonly practiced in the region.

### 7.2.4 SHIFTING FARMING SYSTEMS OR CROPS

**In some cases, climate change will require a shift of crop or system.** In waterlogged areas and in zones receiving extreme rainfall, cassava culture might require a shift to more water-tolerant crops or the improvement of drainage systems. These adaptation strategies may be required in hotspots such as Mondulkiri, Khammouan, and Sakon Nakhon Provinces. Similarly, soya culture in Mondulkiri and Kampong Thom and sugarcane and maize culture in Khammouan may require shifts to more flood-tolerant crops and to heat-tolerant crops in the case of soya. However, given past experiences with the agriculture sector in the LMB, those shifts will be shaped mainly by market demand and prices unless assertive policy and extension service support is provided by government.

[55] For example, *Stylosanthes,* Job's tear (*Coix lacryma-jobi*), rice bean (*Vigna umbellata*), and *Cajanus*.

### 7.2.5 ALTITUDE SHIFT

**Rubber will need to shift in altitude in several provinces such as Mondulkiri and Chiang Rai to avoid increasing temperature.** Altitude shift will also concern other perennial plantations in specific spots within the LMB like Litchi production in northern Thailand (Chiang Rai), and Robusta coffee in the Vietnamese Central Highlands. Those shifts will be needed in the medium to long term. Production in current areas might be replaced by more heat-tolerant crops.

### 7.2.6 BUILDING ON PRACTICE AND EXPERIENCE

Adaptation strategies presented here for developing more resilient production systems are based on previous experience and testing in the region. Production systems are extremely diverse when explored at the farm level, with variations existing in the diversity of soils, water management capacity, access to markets, knowledge, inputs, and equipment. Ultimately, provincial or ecozone-wide guidance on adaptation will need to be considered and adopted as relevant through locally-defined adaptation strategies.

Interactions with other influential sectors have not been explored in depth, for example economic and market forces. Market drivers and national policies concerning landuse, infrastructure expansion or agriculture priorities can have greater immediate influence at the local and provincial level than changes in rainfall patterns or temperatures.

This study has highlighted the key threats and set out adaptation solutions and directions that can be investigated at the local level to arrive at appropriate adaptation plans. The findings and recommendations proposed here should be validated at the community level and discussed with local experts in designing tailored adaptation measures. At the same time, there is much that can be done at the national and provincial level to provide the right enabling environment, incentives, and supports for adaptation planning and piloting.

## 7.3 LIVESTOCK

Due to the diversity of livestock-raising systems in the LMB and the wide range of specific constraints and opportunities at the local level, the potential adaptation strategies to increase climate change resilience and strengthen household livelihoods described here are intentionally broad and flexible. The approaches presented offer a means of considering livestock systems strategically, and to guide design of specific interventions at the local level.

The adaptation options are applicable to the large majority of livestock systems in the LMB. Specific areas where constraints are greatest have been identified. This strategic approach is intended to support locally-targeted livestock development interventions under threats of climate change to 2050. A more specific action-oriented planning methodology and options are provided in the livestock theme report for identified hotspot provinces as well as in the context of ecozone and the overall basin.

### 7.3.1 PRINCIPLES GUIDING ADAPTATION IN LIVESTOCK SYSTEMS

*Improving livestock nutrition, health, and market access* throughout the watershed will improve household and stock resilience to climate change and should be a guiding principle for LMB general livestock adaptation planning. Specific adaptation interventions, however, including prioritization and phasing will require local-level consideration and decision making.

To enable positive development in livestock systems and increased resilience to climate changes, five key aspects of livestock production have been identified for adaptation interventions:

(i) Nutrition
(ii) Disease management
(iii) Management of the production environment
(iv) Production planning, breeding, offtake, and genetics
(v) Access to markets: both upstream and downstream

The five aspects are all closely interrelated but have been separated to promote consideration of livestock production constraints from a range of perspectives. They may be considered under the two broad categories of "production" and "market" factors. Making positive improvements in these aspects of livestock production will likely enhance both household and livestock resilience to climate changes, support other household livelihood mechanisms, and reduce local and broader environmental pressures including threats to protected areas. The strategic considerations are generally applicable to all major smallholder production systems currently operating in the LMB, and are particularly important for low-input smallholder systems and small commercial units. They do not target larger-scale operations although there would likely be significant indirect benefits to these businesses through trade, reduced disease threats, and the potential to access new and higher-value markets domestically and potentially internationally.

The following subsections expand on the five key livestock adaption concepts and provide examples of areas where activities may be most applicable and urgent. Where the term "smallholders" is used it refers to both low-input scavenging and grazing poultry, pig, and ruminant systems and more commercially-orientated small- and medium-scale pig and poultry units. These broad categories were defined for this main synthesis report; greater differentiation and depth is provided in the livestock theme report.

### 7.3.2 NUTRITION

**Reduce undernourishment/improve feeding quality by increasing the quality and quantity of feed production and storage and the nutritional balance of diets.**

**Adaptation rationale: increasing internal adaptive capacity of livestock**

Adaption options should first consider smallholder access to feed and feed quality on an annual basis, noting seasonal peaks and troughs. In much of the LMB smallholder stock, particularly ruminants are generally in poor condition during the late dry and early wet seasons. During these periods, stocks of all species generally lose value and productivity. They experience reduced ability to work and reproduce and they have decreased weight and production of non-meat products such as milk, eggs, manure, and feathers. The threat of disease is increased with impaired immune system responses in some cases associated with undernourishment.

Improved use of current feed resources, such as crop residues and locally available uncultivated forages, and introduction or improvement of forage cultivation will help reduce periods of nutritional deficiency. Available protein is typically the key nutritional component to address, although energy may also be lacking, while some areas also endure chronic mineral deficiencies such as phosphorous deficiencies in parts of Lao PDR. In many cases nutritional deficiencies may be alleviated easily through supplementation. However, this requires knowledge transfer and access to appropriate feed additives, such as molasses for energy and leguminous supplements for improved amino acid balance in monogastric diets (which would also likely benefit many ruminant diets). Local assessment of feeds is required.

The appropriate forage varieties will depend on local availability, growing conditions, and typical landuse such as major crop systems. Alternatively, concurrent introduction of feed preservation techniques, such as small-scale silaging can reduce pressure on stock during lean periods. Further, feed treatments that improve digestibility through chemical or physical means, e.g., use of urea treatments on straws and/or chopping or grinding of fibrous feeds to increase availability of nutrients. Advances in forage and crop breeds should also be monitored. Organizations such as CIAT provide an excellent source of information on improved forage varieties and other organizations such as IRRI conduct research and breeding programs targeting both resistance to adverse conditions and improved nutrition of crop byproducts. Some of these new varieties, such as salinity- and flood-tolerant rice cultivars, would likely be of value to producers in the region now and are likely to remain valuable under future climate conditions.

Improvement in the genetics of livestock might also help in terms of feed conversion efficiency as a possible means of reducing pressure on available feed resources. However, higher feed efficiency breeds bring other challenges which would need to be assessed in the given situation. For example, they may have lower natural disease resistance depending on the breed, and they may require more careful management and diet formulation if they are to flourish.

Improving feeding systems will also reduce pressure on the local environment and protected areas commonly used for grazing large ruminants. Reducing the need to graze non-agricultural areas will reduce contact with wild species such as banteng (of which the largest known population inhabit eastern Cambodia) thereby reducing the risk of disease transmission between wild and domesticated species. Limiting the need for grazing in protected areas will also reduce contact between people tending stock and wild animals, which may reduce hunting pressure.

Undernourishment is a key constraint to smallholder low-input systems particularly in areas prone to drought and flooding. Grazing animals are particularly threatened in hotspot provinces Mondulkiri and Khammouan, although in general undernourishment is a current and future threat to low-input systems throughout the LMB.

### 7.3.3 DISEASE MANAGEMENT

**Reduce threat of disease by increasing internal disease resistance through improvement of nutritional status and body condition and vaccination levels; and to also reduce disease challenges by improving biosecurity levels (at the herd/flock, village, and regional level) and by increasing surveillance capacity.**

**Adaptation rationale: increasing adaptive capacity (internal and external)**

Disease issues present a significant threat to all stock in the region. Morbidity and mortality are major constraints to livestock productivity and value and limit access to potential markets. Further, disease responses can include culling and market restrictions including movement bans implemented during outbreaks. Market issues are discussed further below.

Climate change is one factor among a number that will alter disease patterns and prevalence. There is strong empirical evidence of shifts in disease patterns in Southeast Asia and the emergence of new infectious diseases is inevitable. Increasing human and livestock populations and increasing production intensity, movements, and contacts in even the most remote areas of the LMB suggest that emerging and endemic disease risks will increase. Further, drier dry seasons and heightened risk of flooding are likely to exacerbate current nutritional problems; while wetter wet seasons increase key infectious disease risks through the effect on vectors and by allowing key pathogens, particularly bacteria, to survive longer outside their primary hosts, increasing the risk of transmission by fomites.

Reduced productivity and mortality due to infectious disease are a problem for all stock in all systems, though the specific disease threats vary with production system. The highest risk systems are small and medium commercial enterprise operators, whom invest substantially in buildings, stock and feed. Several factors make financial risk associated with disease particularly high for these producers—i.e., higher investment, stocking rates, the use of more productive but less resistant improved genetic lines, suboptimal employment of biosecurity measures and variable vaccination quality and coverage, particularly in more remote areas.

Outbreaks of infectious diseases are a key constraint to livestock producers in the LMB. Diseases prioritized by governments on the basis of impacts on stock health and trade include: Newcastle disease, fowl pox, and fowl cholera in chicken production; hemorrhagic septicaemia, foot and mouth disease, blackleg, brucellosis, and sporadic cases of anthrax among bovines; and classical swine fever (CSF) and porcine reproductive and respiratory syndrome (PRRS) in pigs. Regular outbreaks cause significant morbidity and mortality losses and responses to outbreaks have significant economic ramifications for producers. While the infectious diseases listed are prominent chronic problems including a variety of parasites and fungi, less acute bacterial and viral pathogens also cause significant losses, particularly among young stock and in terms of productivity in older animals. Special health interventions targeting these animals are necessary.

The diseases identified are endemic in much of the LMB, however, areas such as Kien Giang, with high human and livestock populations and density and greater numbers of commercial units, are likely to suffer most from these and emerging infectious diseases.

Low-input systems generally use minimal vaccination and employ limited biosecurity measures and are frequently affected by disease outbreaks. Vaccination coverage is low among these systems. In addition, there are issues surrounding vaccine quality due to the availability of inferior products and breaks in cold chains. The threat of disease will also be heightened by poor nutrition which can suppress immunity and is often associated with suboptimal management. Rapid sales after a flood, for example, also increase the risk of pathogen transmission and are events which are likely to occur more frequently and with greater intensity in the future. Smallholders in areas affected by seasonal changes and heightened risk of flooding and drought are likely to experience greater prevalence of key livestock diseases.

*Climate change will affect outbreaks of infectious disease; the frequency and scope of endemic and emerging infectious diseases are expected to increase.* Building capacity in disease surveillance and response to outbreaks can reduce costs of infectious disease outbreaks to producers, by reducing production losses and the effects of disease responses through early recognition of disease outbreaks and improved timeliness and coordination of control measures.

Disease risks also threaten wild species such as banteng. The risk of transmission both to and from wild, feral, and domesticated animals is likely to increase in the future through changing feed availability leading to increased grazing in protected areas. Changes in disease patterns and the health status of domesticated stock are likely to affect wild populations, and vice versa.

Livestock adaptation strategies need to consider improving livestock disease management through a variety of approaches including rearing of stock suited to the local conditions, improving nutritional status, increasing quality and coverage of vaccinations and parasite controls, earlier recognition of clinical signs and more accessible treatment measures, and finally reducing disease challenges through improved biosecurity measures. Building animal health service capacity is a priority in many areas of the LMB. Higher levels of farm support are needed in delivery of extension services, technology transfer and disease surveillance, and responses utilizing effective delivery systems which maximize training ownership and outcomes.

### 7.3.4 MANAGEMENT OF THE PRODUCTION ENVIRONMENT

**Improve livestock-raising conditions through housing location and design to maximize natural ventilation and minimize risk of pathogen entrance and transmission and exposure to extreme events.**

**Adaptation rationale: reducing exposure of sensitive systems**

Incorporation of housing and confinement systems can help reduce the risk of disease as they provide a physical barrier to traffic and mixing, decreasing the risk of pathogens entering the herd or flock. Further, with expected increases in average temperatures and periods of extremes, stock housing should be located and designed to maximize natural ventilation, with the goal of reducing heat stress-related issues, particularly behavioral problems and reduced feed intake. Selecting more heat-tolerant breeds and strains should be considered in parallel; for example, selective introduction of light feather genes into commercial poultry lines could increase productivity under predicted conditions. This strategy would not be applicable to those not employing high-performance breeds.

Improving management in provinces in northeast Thailand, central and southeast Cambodia and the Vietnamese Delta areas where commercial pig and poultry units are most common would be the priority from the perspective of heat stress. The hotspot provinces of Chiang Rai and Kien Giang show less extreme temperature increases, but the number and importance of small commercial pig and poultry enterprises, the increasing competition from larger-scale corporate producers, and the high human and livestock population density make improved housing and confinement a key adaptation strategy. Often the key limit to improving management of the production environment is access to capital. For this reason, access to rural credit may be a key starting point for effective adaptation.

### 7.3.5 PRODUCTION PLANNING, BREEDING, OFFTAKE, AND GENETICS

**Improve production planning and reproduction management in breeder herds/flocks, for example, reducing inbreeding, recognition of estrus, and earlier weaning.**

**Increase offtake rates, where beneficial, for example promote controlled destocking to reduce pressure on stock, land and/or nucleus herds and flocks with the additional benefit of increasing household incomes.**

**Introduce improved productivity/tolerant genotypes.**

**Adaptation rationale: reducing exposure and sensitivity, increasing internal adaptive capacity**

Current low-input system resilience to climate change is reduced by limited production planning particularly among cattle raisers. Improved production planning targeting demand peaks can increase household incomes while reducing pressure on feed resources and the need for grazing in protected areas. Improving rates of reproduction through better breeding management, altered diets, and improved animal health management (notably aflatoxin problems in pigs) can increase progeny over the animal's productive lifetime.

Alternatively rearing more metabolically and productively efficient breeds may meet household requirements at lower cost to other household resources, although disease resilience and other potential management issues would require additional consideration. Greater efficiency in stock management and sales can increase household access to and income from draft and manure if managed well. Increasing planning and offtake also provides a potential incentive for households to invest more in animal health benefiting all producers by reducing disease risk.

Increasing offtake rates will be most beneficial in areas prone to extreme events such as drought and flooding. Areas such as Mondulkiri, Khammouan, and Gia Lai have large populations owning small herds of cattle and buffalo raised in low-input, low-productivity systems. Low feed periods and poor stock condition are particular problems in Mondulkiri and Khammouan. Low-input scavenging poultry and pig systems will also generally benefit from greater planning in reproduction and reduced time to sale. Scavenging poultry are often kept beyond six months, and extensive pigs above 12 months, by which point weight gain is negligible. The advantages of maintaining stock beyond this point are outweighed by the increasing risk of loss to disease, and predators in the case of poultry.

As systems develop in terms of animal health practices the gradual improvement of genetics through the introduction of more productive lines might be considered. However, modern genetics are usually less able to cope with the high disease challenges present in the LMB. They require higher-quality diets to thrive and are generally less resilient when threatened with temperature extremes. Upgrading genetics can be high risk and should be considered with caution. Breeding programs utilizing local genetics would be lower risk and potentially very valuable given the many advantages a number of local breeds exhibit in terms of reproduction, heat tolerance, and disease resistance. However, careful introduction of appropriate improved lines through crossbreeding can have significant productivity benefits if well managed, and can encourage greater investment in stock with greater returns presenting the potential to increase livestock-derived income from this sector.

### 7.3.6 ACCESS TO MARKETS

**Increase access to input and output markets and producer organizations to reduce input costs, increase prices received, and reduce price volatility.**

**Adaptation rationale: increasing adaptive capacity, reducing sensitivity**

Employing value chain-based approaches to assessment and project design can allow a holistic approach to livestock development. It has the potential to increase efficiency along the chain in terms of the socio-economic and biophysical threats associated with climate change.

By increasing access to markets upstream input costs can be reduced and stabilized. Crowding in business leads to greater competition to supply and improved quality of products available. Greater access to feed suppliers, genetics, and animal health products and services will increase productivity and resilience to extreme events, seasonal changes, and temperature increases associated with climate changes. For example, more isolated areas are under greater threat from local events, such as localized flooding and drought, which can decimate feed resources—improved ties to other markets reduces those threats by allowing access to necessary inputs and smoothing input price volatility.

Greater access to output markets increases producer price-setting power and transparency and accountability of middlemen and traders. Higher-value urban markets are increasing in size with rapid urbanization; unlocking these markets for smallholders presents enormous potential for income generation through greater margins and price stability. Increased competition can incentivize better practices such as use of vaccinations and employment of biosecurity measures, reducing disease risks. Enabling smallholder access to new markets requires the provision of adequate physical access through infrastructure; increased linkages between producers, middlemen, and traders; and may require greater producer organization to improve stability of supply and food safety awareness and assurance, e.g., slaughtering hygiene and cold chain development.

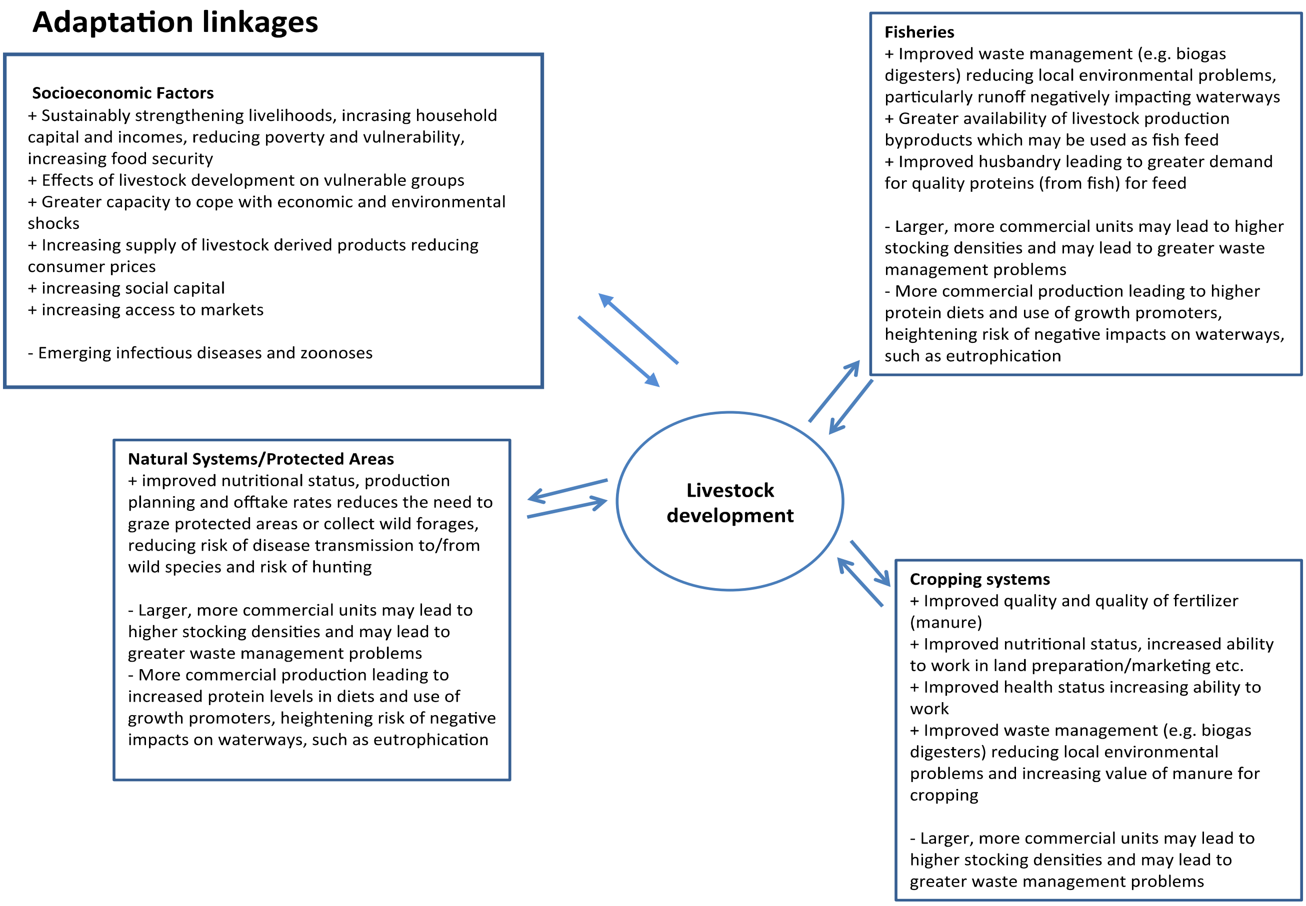
Access to usable market information and increasing linkages between value chain actors further promote transparency and accountability in negotiations while increasing social capital. Increasing social ties will likely strengthen household livelihoods and resilience to climate change threats. Second generation market information systems are most applicable and based upon network development and strengthening, which can be more sustainable, dynamic, and adaptive. The extensive mobile phone coverage in the Mekong region has allowed ICT-related formal and informal systems to become established. Continuing this development is likely to increase producer resilience to climate change threats in the longer term.

Market access is most limited in remote areas such as Khammouan, Mondulkiri, and to a lesser extent areas of Gia Lai and Chiang Rai. These areas can remain competitive with increasing integration with markets due to the relatively high availability of land for grazing and forage cultivation, relatively low costs of production, and current market preferences for local, slow-growth breeds.

### 7.3.7 ADAPTATION LINKAGES

Figure 7-2 identifies some of the key potential positive (+) and negative (-) feedbacks of livestock adaptation strategies on other livelihood incomes. The identified considerations are not exhaustive.

**Figure 7-2: Livestock adaptation linkages**



### 7.3.8 BUILD ON SMALLHOLDER ECOLOGICAL FARMING SYSTEMS

This study has found that integrated systems of raising livestock strengthen livelihoods while increasing resilience to climate change.

As the livestock sector continues its rapid development in the LMB, the competitiveness of small- and medium-scale commercial production will diminish, due largely to competition from larger-scale producers; but these smaller commercial systems are also susceptible to the effects of climate change. Wealthier households typically operate small commercial units that are more likely to produce negative externalities, such as local pollution, potentially weakening other livelihood mechanisms in the local area. Meanwhile, smallholder, low-input systems can remain both viable and locally valuable due to their broader contributions to household livelihoods and through use of hardier, more climate-tolerant breeds.

Livestock products of slower-growth local or crossed genetics remain strongly preferred by many consumers in much of the LMB. Further, the low costs of production and high value of non-meat products, such as manure and traction, make continued smallholder livestock raising economically rationale. Increasing the efficiency of these production systems and ensuring these systems continue to contribute optimally to broader farming and livelihoods will increase resilience to climate change while reducing household poverty and vulnerability.

Current smallholder rural livelihoods are centered on integrated farming systems. These systems are broadly resilient due to the diversity of income and food streams—i.e., risks are spread amongst various livelihood options. Building on smallholder 'ecological farming systems' through introduction of more effective management practices outlined within this section can increase stock value and household incomes. Employment of livestock in ecological farming systems provides manure and draft for land preparation, tillage, and rent, while also increasing crop and horticultural productivity through the benefits of intercropping forage cultivars, particularly legumes, which increase nitrogen fixation and therefore yields. Intercropping of select forages can also reduce pest problems.

The use of nitrogen-fixing forages in intercropping or rotational systems can reduce the use of fertilizer and pesticides, reducing the risk to local waterways and other natural systems. Further, by increasing the availability of feed, the need to graze bovines in protected areas will be reduced, reducing pressure on remaining natural systems and threats to endangered species.

Building on already integrated crop-livestock production at the smallholder level has the potential for long-term benefits for livelihoods and increased resilience to climate change, while reducing the burden and negative effects of current production on other systems. This approach will target the poorest and most vulnerable households. Supporting smallholder livestock systems builds household-coping capacity, can target vulnerable household members, and can benefit household income and nutrition.

## 7.4 CAPTURE FISHERIES

Identifying adaptive climate change measures that can reverse declines and protect resources and stocks for the capture fisheries faces four major challenges.

- The overriding influence on the capture fisheries of the Mekong will be **the development of dams for hydropower**. Climate change will be something of a side issue to the more immediately drastic effects of dams; potentially important but more subtle. The study can assess the effect of increased temperatures on migratory fish in the upper Mekong, but that assumes that migratory fish can reach these areas. The planned dams may make some climate change considerations all but academic.

- The second challenge is that capture fisheries by their nature **are open systems and their productivity depends more on natural variations than on planned controlled management**.
- Third, the sheer size of the capture fisheries areas means that **adaptation actions, to be effective would need to be large scale and therefore probably expensive**.
- Last, given the extensive "noise in the system", which affects year-to-year production from the capture fisheries, **measuring the impact of any adaptation effort is likely to be a considerable challenge.**

In the SE Asia region, there is a growing trend towards encouraging fishery managers to adopt **ecosystem-based approaches to fisheries management**, i.e., fisheries management that focuses on stocks and the ecosystem sustainability; not just stocks. This approach will become all the more important as the climate warms and the weather patterns become less predictable**.**

For each of the fish types, the following adaptation measures are needed.

**For upland fish, in order to protect the stream environments, forest cover needs to be retained or recovered. Protection of valley catchments is needed to reduce the effects of flash flooding so that the specialist upland fish species can remain prolific.**

- These upland streams should be kept intact to maintain alternate shallow fast-flowing areas to increase water DO levels and deeper pools in which fish can rest when conditions dictate.
- New pools can be created through diverting currents. These pools will need de-silting from time to time, so that they stay attractive to fish.
- Low weirs can be used to retain water during the dry season in some areas.
- The creation of varied habitat areas along the stream course will also provide protection and allow for more species to co-exist.
- These technical measures would have to be accompanied by the establishment of conservation zones, where local people did not fish at certain times of the year.
- Support to communities to manage their own upland fisheries for sustainable use, should be encouraged. The organized trapping of invasive species may become necessary.

**For migratory white fish, the focus should be on improving their access to spawning grounds, and the habitats in those areas. This includes restoration and effective protection of the flooded forests around the Tonle Sap and lower Mekong, which are vital to the health of the fishery and the migratory species that live there**.

- This strategy may mean the seasonal dismantling of some structures in the tributaries that prevent the movement of these fish species, such as small-scale hydro or irrigation installations.
- The seasonal protection of stocks in the deep pool areas of the mainstream should also be promoted in the communities who depend on these resources.
- Involving communities in recording catches for specific migratory species is needed so that trends in fish numbers and sizes can feedback to adjustments in management.

- Where populations of endangered fish cannot be supported through habitat and fishing protection, their artificial propagation in hatcheries and the subsequent release of juveniles into the capture fishery can help maintain viable fish populations. This is already being done by the Fisheries Department in Thailand in the case of the giant Mekong catfish (*Pangasionodon gigas)*.

**Although the black fish species of the LMB do not look particularly vulnerable to the changing climatic conditions, steps are still needed to ensure their biodiversity remains intact and their contribution to productivity remains high.**

- The single most important management intervention for these fish species is the creation and management of dry season refuge areas, from which they can repopulate the floodplains each wet season**.**
- The creation of reservoirs through damming of Mekong tributaries will almost certainly damage parts of the fishery; they will also create new environments that may suit these types of fish. Fish catches from these new environments could contribute significantly to local food security and livelihoods.

**For estuarine species, the replanting and effective protection of mangrove forests and mud flats in coastal areas can do much to protect against erosion resulting from sea level rise, storms, and increased flooding, and thereby help maintain fish biodiversity and production.**

- Non-interference with natural tides and current patterns is also required to ensure that mangrove areas remain healthy and able to support the estuarine fishery.
- Certain areas must be protected from both fishing and wood collection as core breeding, nursery, and feeding areas.
- Special protection and management measures may be necessary for some sedentary species such as mollusks. This might entail the installation of substrates followed by seeding of spat, in these new areas.
- Co-management of coastal fisheries involving both local communities and governmental agencies may be practical and effective in some cases.

**In specific locations, a number of key species considered the most valuable and vulnerable to climate change will need specific protection and enhancement measures**. These adaptations will need to be species and habitat specific and should be integrated with programs to reduce fishing pressure on the valuable stocks and habitats. Communities must be involved in such initiatives but they may need to be initiated by government departments, possibly supported with fishery laws aimed at protecting the most vulnerable species.

**In all areas, the monitoring of invasive aquatic species should be conducted at a range of levels (community and government) to monitor the spread of species which harm the resilience of native species and their habitats. Eradication drives may be necessary to keep some invasive populations in check.** Community awareness of invasive species should be raised through a range of media and people should be encouraged to report unusual sightings and catches.

**Finally, despite the threats and uncertainties, it should be remembered that fishing communities in SE Asia are extremely resilient to the vagaries of the weather and seasons, which in the case of the Mekong River and floodplain are already extreme.**

There will be an inherent capacity to adapt and change practices based on the prevailing conditions of the time. The question is whether climate change pushes some communities into areas where their traditional management tricks and mechanisms no longer work effectively.

## 7.5 AQUACULTURE

**Aquaculture due to its diversity of systems, scales of production, inherent manageability, and control of environments offers more scope for adaptation to climate change than capture fisheries.** However, some intensive systems, such as *Pangasius* farming in the delta, are already pushing the limits of production from their systems and already suffer regular losses through disease and water quality problems. These problems will only increase as climate change effects are felt.

**The more intensive systems will tend to have the greatest adaptive capacity** due to the high level of investment and management (although there are limitations). However, the vast majority of aquaculture practiced in the LMB is extensive or semi-intensive and is open to the elements with little contingency for managing climate change issues outside of a few simple preventative measures. These may be enough for the present and near future but may fall short of securing the production systems for the extent of climate change extremes expected.

**In intensive systems:**

- Some climate change threats can be managed through **advanced technology** (such as aeration) although this may be costly.
- If this is not practical, climate change threats can be managed through changes to the intensity of the culture system, the species raised, and the use of other inputs.
- **For super-intensive systems, the eventual solution may be to move fish production 'inside', i.e., within buildings where the environmental conditions can be completely controlled**. This would be accompanied by efficient water bio-filtration and reuse. The technology to do this has already been developed in Europe and the US and will probably be copied once the climate makes other adaptive measures too unreliable

**The CAM vulnerability assessments for the hotspot areas** have identified the following adaptations, which mainly focus on managing increased temperatures, dry season water supplies, and flood control. Most of these measures apply to different production intensities including intensive, semi-intensive and extensive.

- Increased temperatures may make upland and mid-level areas, currently sub-optimum in terms of growth, more suitable for aquaculture. In these areas, ponds should be exposed to full sunlight for as long as possible and not be shaded.
- **However, in lower elevations, projected temperatures will be above optimum for many species and adaptation measures will be required. This may mean shifting from carp species to tilapias, which are generally more tolerant of high temperatures and low DO levels.**
- **Farmers may have to adjust fish culture cycles and stocking densities to manage around expected high temperature periods.**
- High temperatures can be offset to an extent by regular aeration of deeper ponds to prevent stratification and therefore risk of water column turnover.

- And reduction in the use of low-value fish for aquaculture feeds, in favor of pelleted feeds may be necessary to maintain water quality.

**Many aquaculture farms may have to invest in on-site water storage to reduce the risks of reduced water availability during the dry season**.

- For intensive farms, reuse of pond water will be an important strategy to reduce water use, and release of effluents to the environment. In most cases, water will have to be pumped from the reservoir, as required. If possible, water should be fed to the ponds by gravity.

- Weak embankments and sandy soils may have to be strengthened through the addition of clay soils to some ponds, to prevent water loss through seepage.

**The strengthening of pond embankments to protect against flooding will be necessary in many areas**. This may be a significant cost with large-pond systems, such as shrimp farms, and may result in the investor giving up and leaving the site.

- Some species are more prone to leave a flooding pond than others. For example, silver barb will leave at the earliest opportunity, while other species, such as *Pangasius* catfish and Chinese carps are more reluctant.

- Protecting ponds from flash flooding offers more of a challenge as pond embankments may be eroded in such cases and need reconstruction. Diversion canals may have to be dug to channel water away from vulnerable pond areas.

- If flooding becomes unmanageable, then culture cycles would have to be adjusted so that fish harvests are timed to occur before high-risk periods.

**In coastal areas, farmers should be able to manage salinity levels quite well through their choice of species, some being tolerant of a wide range of salinities.**

- Many shrimp ponds are shallow which can result in a rapid reduction in water salinity after heavy rain, early in the wet season. This can increase stress levels in the shrimp and make them more susceptible to diseases, including WSSV.[56]

- **Conflict between shrimp farmers and rice farmers may increase as sea levels rise and it becomes more difficult to manage salt water**. Integrated water management plans will need to be implemented in many areas to contain these types of conflicts.

- Giant freshwater prawn farmers in the delta may shift to penaeid shrimp culture as sea levels rise. This poses the interesting question of what to do with derelict coastal shrimp farms, if they become unmanageable due to sea level rise. Many of these ponds in the delta would have been mangrove forests before they were cleared for shrimp culture. **Efforts should be made to redress this situation through the replanting of mangroves for protection and encouraging siltation. These areas may not return to mangrove forest without help.**

- Climate-friendly systems, e.g., tiger shrimp/crab production in mangrove replanted areas of the delta should be more widely promoted.

[56] White Spot Syndrome Virus

**The creation of reservoirs will create new environments that can be used for cage aquaculture and possibly culture-based fisheries which will create new livelihood opportunities for some local people.**

- However, only sheltered sites will be suitable as these systems are vulnerable to storms, which can damage infrastructure and result in loss of stocks.
- **Finally, the creation of small on-farm ponds, as promoted by Thailand's King Bhumibol for several decades, can be viewed as an excellent local climate change adaptation strategy** for a wide range of farming activities that are reliant on rainfall. This includes both the agriculture crop and livestock sectors.
- Multi-use ponds will benefit small-scale aquaculture as well as allowing for the trapping of wild fish from the local capture fisheries, thereby helping rural households meet their food security requirements.



## 7.6 NATURAL SYSTEMS – NTFPS AND CWRS

The different options for enhancing the resilience of NTFP and CWR species may be grouped under several broad adaptation strategies for the LMB:

- Habitat protection
- Habitat rehabilitation and reforestation
- Water management of habitats
- Species protection
- Sustainable management of NTFP harvesting
- Domestication and cultivation of NTFPs
- Monitoring and research
- Selection of resilience within species
- Assisted movement of species at risk and shift of habitat

Those strategies are described here with the short-, medium- and long-term interventions identified in tables following each strategy. Some strategies are required at several time scales.

### 7.6.1 HABITAT PROTECTION

**Habitat protection is the most fundamental conservation and adaptation measure for all NTFPs and CWRs** (Table 40). If the forest or wetland area where they live is damaged through deforestation, illegal logging, drainage, and/or landuse change for monoculture plantations and agriculture, the species will be less resilient to climate changes. If the species is already stressed because of habitat damage or loss, climate change could potentially push the species to local extinction.

*The principal habitats where NTFPs and CWRs survive are in protected areas.* Habitat protection may be provided within and outside the protected area system. Sometimes key habitats are not covered by any form of conservation management and tenure. In such cases, protected areas will need to be extended to include all key habitats. In any case, protected area management is often neglected, under-funded, and in need of strengthening. Many protected areas may be poorly managed, with habitats continuing to degrade and natural resources being unsustainably removed. There is much to do to strengthen the management and status of protected areas so they can provide the backbone for adaptation strategies in farming ecosystems and rural livelihoods. Countries such as Vietnam, where the protected area estate is relatively small and unrepresentative of many habitats should actively expand the system and introduce closed-door policies and enforcement for illegal exploitation.

**Table 40: Phasing of habitat protection strategies**

| | Short term | Medium term | Long term |
|---|---|---|---|
| Habitat protection | Increase management effectiveness of 'Protected Area Systems' to reduce deforestation, commercial and illegal logging, encroachment, forest fires, landuse change, intensive mono-cultivation, and habitat deterioration and loss. | | |
| | In areas with strong waves, bioengineering wave-breaking structures are needed to protect the young mangroves trees from being destroyed by waves. | General protection of forest habitats and wetlands to ensure survival of wild plants. | Enhance and increase protected habitats appropriate for particular species considered to be at risk. |
| | Protect and conserve natural habitats and important ecosystems for wild rice. | Advocacy to establish and strengthen the management of protected areas. | Protection for identified stopover points for honey bees. |
| | | Increase the coverage of protected areas to maintain habitats and to safeguard the existing wild population at national and local levels. | |

## 7.6.2 HABITAT REHABILITATION

**Rehabilitation and enhancement of habitats, both forests and wetlands, is one of the most important and immediate adaptation strategies** (Table 41)**.** Rehabilitation is essential for ensuring the survival of NTFPs and CWRs within and outside protected areas. Many habitats are already degraded and reforestation is necessary to restore them so they can continue to provide shelter for the assemblage of plants and animals. A variety of mixed key species should be chosen for replanting. The choice may follow the principles of the "framework species method", which is designed to restore diverse forest ecosystems on degraded forestland for biodiversity conservation and/or environmental protection. Framework species are foundation trees and shrubs in an ecosystem. They can form fast-growing and dense crowns that rapidly shade out competing weeds, and are attractive to seed-dispersing wildlife, especially bats and birds.

In Cambodia this method has been demonstrated. The framework species method "depends on some tract forest patches or remnant forest trees, surviving fairly close to planted plots, to provide a source of seeds. In addition, reasonably dense population of seed dispersing animals must occur in the vicinity. This can be achieved by planting a mixture of 20-30 native forest species (including fruit bearing species). Tree planting restores basic ecosystem structure and function, whilst seed-dispersing wildlife re-establishes biodiversity and the original tree species composition of the forest. If either of these two elements is missing from the surrounding landscape, natural regeneration within framework species plots may be unreliable. On such sites, if the initial planting of framework tree species failed to stimulate natural regeneration, subsequent planting of additional tree species may be necessary."[57]

---

[57]Forestry Administration/Cambodia Tree Seed Project/DANIDA, 2005. Guidelines for Site Selection and Tree Planting in Cambodia

Table 41: Phasing of habitat rehabilitation strategies

| | Short term | Medium term | Long term |
|---|---|---|---|
| Habitat rehabilitation, reforestation | Restore and rehabilitate deteriorated forests. | Re-establish mangroves along the coast through planting and natural regeneration. Consider use of several species to cope with storm damage. | Reintroduce declining or lost species to existing protected areas. |
| | Increase forest canopies, crown covers, and shady areas. | Establish and protect "buffer zones" for existing forest areas in order to allow natural shift of forest distribution under future climate change. | Through landuse planning, leave enough space for establishment of mangroves along the coast, including relocation of the planned coastal dyke further inland and use of flexible bioengineering methods. |
| | Use framework species method to re-establish mixed forests ecosystems. | Enrichment planting of flowering plants at honey bee stopover points and for other important pollinators. | |



### 7.6.3 WATER MANAGEMENT IN HABITATS

**Water management for conservation of NTFP and CWR species is an essential adaptation strategy** (Table 42).

It is important both for the continued functioning of wetlands and for maintaining soil moisture in the NTFP habitats. Soil moisture availability is a critical factor in the survival of most NTFP species. Many of the most important species found in forests have a preference for areas that are wetter, growing along the banks of streams or pools (trapeangs in Cambodia) within the forest. Increased risk of drought is likely to change these areas of higher moisture. The construction of flexible check dams in streams and bioengineering measures will reduce the rate of runoff, soil erosion and maintain ground water levels. This form of water management is an adaptation measure which can be undertaken by local communities. The structures are small and easy to construct and maintain.

Wetlands and coastal areas such as U Minh Thuong in the hotspot province of Kien Giang may also require intensive water management to maintain adequate fresh water levels. At a wider scale, integrated watershed management is required to ensure that sufficient good quality water is available, and balanced with other uses. The need to maintain flows of water in rivers to protect ecological services, especially hydrological functions, needs to be factored into water allocation planning. In parts of the Mekong Delta where the extensive canal system drains the land, some protected areas tend to dry out to the detriment of the overall forest habitat. In other areas, where the risk of fire is high, the ground water levels may need to be maintained artificially high.

In mangrove areas, the proposed dykes to counter sea level rise may cut off areas for expansion of the mangroves; the use of softer more flexible measures and the provision of sluice gates to allow the normal movement of saline waters will be necessary for long-term growth and health of the mangroves.

**Table 42: Phasing of water management strategies**

<table>
<tr><th></th><th>Short term</th><th>Medium term</th><th>Long term</th></tr>
<tr><td rowspan="3">Water management in habitats</td><td colspan="2">Build "check dams" to maintain and increase soil moisture availability within the forests, especially during dry season months, to maintain ground water level near areas that may tend to dry out, and to reduce wild fire risk.</td><td>Plan sluice gates together with the coastal dyke to allow saline water to move in and out of the coastal dyke to provide habitat for mangroves and to allow migration inland.</td></tr>
<tr><td>Protect water courses in forests where key NTFPs occur e.g., near stands of Amomum.</td><td colspan="2">Strengthen and systemize the overall watershed management for forest and water resources conservation. Allocate water for ecological services.</td></tr>
<tr><td>Improved management of hydrology in peat areas to prevent drying out.</td><td>Develop "wet season refuge" for earthworms in order to reduce their vulnerability to heavy rainfall, flooding, natural predators, and human threats.</td><td></td></tr>
</table>

### 7.6.4 SPECIES PROTECTION

**Species protection programs will be necessary for some species to reduce debilitating stresses**. National level protection may be required so that species are designated on the national protected species lists, with the necessary regulations and penalties for illegal collection and trade, for example, for protection of wild orchids. If certain NTFP species are placed on protected species lists, an awareness campaign will be required to ensure that people using the species know what is/or is not permitted, the value of the species, and why it needs protection.

Protection may also be given to species by the recognition of their importance to rural livelihoods, so attention is paid to their conservation in biodiversity action plans and plans for other developments. Examples of the need for this type of protection would be the floating rice varieties and wild honey bees. Specific conservation programs need to be developed for those species.

In other instances the protection may be more local, so that existing stands of a particular species may receive focused protection, for example, the identification of honey bee migration routes and stopover points. Another example may be the protection of wild rice from genetic erosion due to proximity to cultivated species.

Finally there are the in situ and ex situ conservation approaches for species protection. Seedbanks may be required to provide the seeds for future rehabilitation of the species in both short and medium term where they have become degraded, or in the longer term when climate change has had significant impacts on range (Table 43).

**Table 43: Phasing of species protection strategies**

| | Short term | Medium term | Long term |
|---|---|---|---|
| Species protection | Ensure that harvesting and cultivation practices do not threaten wild stock. | Propose some threatened NTFP and CWR species for the protected plant list in each country. | Collect seeds and establish seedbanks for ex-situ conservation of threatened NTFPs & CWRs. |
| | Environmental education about importance of protecting NTFP and CWR species. | Better conserve and safeguard the existing wild population in protected areas, promote and enhance in-situ conservation. | National protection status for both in situ and ex situ conservation of species. |
| | Conduct inventories and map existing populations of NTFPs. | Strictly control and properly manage trading and cross-boundary trading of certain threatened NTFP species. | Provide more conservation attention and higher priority national conservation status for honey bees. |
| | Protect exposed plants from strong winds where possible. | Collect seeds, establish seedbank, and produce seedlings and saplings for in-situ conservation and re-introduction to deteriorated forest and wetland areas. | |



### 7.6.5 MANAGEMENT OF NTFP HARVESTING

**NTFP harvesting needs plans, management, and enforcement as an adaptation strategy** (Table 44). Destructive harvesting and over harvesting is an avoidable pressure on NTFP species. In some cases harvesting of NTFPs is non-destructive, e.g., collection of fruit and seeds, but in other cases the whole plant may be destroyed, e.g., collection of bark and roots, or where the main stem is cut down. If this happens then the stock of that plant in the location may be threatened. Pressure from increasing numbers of people collecting the product can contribute to over harvesting to the extent that the plant could become rare or locally extinct. The rising value of NTFPs especially for export means greater harvesting pressure on these products.

**Sustainable management of these NTFP resources will become increasingly important for continuity of valuable community resources, and to build resilience**. Sustainable management may involve development of non-destructive collection and harvesting strategies, or the agreement of limits for collection each year and setting aside areas of forest for regeneration. It may also involve the development of processing techniques that reduce wastage and improve quality so that smaller quantities of the plant need to be collected for higher value. This value-added approach is an important mechanism for involvement of local communities in adaptation.

The development of more sustainable harvesting and processing practices is the same as would be undertaken for any commercial agricultural crop. It requires a clear understanding of the biology and ecology of the NTFP and what constitutes a sustainable harvest. It needs research into harvesting and processing techniques, as well as discussion and negotiation with and between community members on their application. It is not enough to promote sustainable harvesting. There must be a clear incentive for its use otherwise the original destructive methods will continue.

Over harvesting may be the result of local people collecting more of the product, but it often results from people coming in from outside the locality to harvest the product in season. People outside the local communities need to be aware of less destructive harvesting techniques and the limits to which the product can be collected. They are less easy to influence and to ensure compliance with local agreements on practices and limits. If collection by outsiders makes up a significant proportion of the harvest, then monitoring and enforcement by local communities becomes necessary, as well as provincial and national government action to raise awareness and to help enforce local management plans and national regulations.

**Table 44: Phasing of sustainable harvesting strategies**

| | Short term | Medium term | Long term |
|---|---|---|---|
| Sustainable harvesting | Encourage and support efforts of local communities to achieve 'sustainable use and conservation' of NTFPs. | Improve marketing to increase profit margin of NTFP use to increase livelihoods, and reduce pressure on resources. | |
| | Ensure harvesting practices are sustainable and avoid over exploitation. | | |
| | Develop processing and use to reduce wastage and use of raw materials from NTFP species, and hence reduce pressure on resources. | | |

### 7.6.6 DOMESTICATION AND CULTIVATION

**Another adaptation measure for reducing pressure on the wild stock of NTFPs is through cultivation and domestication of the plants.** Already a number of NTFPs have been domesticated, for instance cardamom and paper mulberry, orchids, and mushrooms. Cultivation has a number of advantages for the producer; the plants are grown in a clearly identified place, so ownership is more evident and collection is less time consuming. The quality of the product is often better and achieves a higher value.

However, cultivation in situ may mean that some parts of the forest ecosystem are disturbed and dedicated to cultivation of only one species. For example, in some areas cultivation of cardamom in clearings in the forest is becoming destructive of the forest ecosystem. With increasing concentration of the plant, problems of disease and pest attack increase. Cultivation outside of the forest boundary has been demonstrated as in the case of plantations of paper mulberry.

Not all NTFPs can be domesticated and cultivated—some depend on the forest ecological assemblages, which are impossible to recreate in an artificial environment.

A different perspective on cultivation practices is the influence on the genetic integrity of the wild stock. Wild rice stocks are under threat from cultivation of commercial stocks almost as much as commercial seeds may be contaminated by "weedy rice". Where wild rice stocks are known to exist and recognized as important in situ genetic resources, it may be necessary to restrict the interactions with cultivated stocks. In a somewhat similar way, the use of agricultural chemicals along the seasonal migration routes and known stopover points for honey bees may need to be modified to reduce the risks to honey bees (Table 45).

**Table 45: Phasing of NTFP domestication and cultivation strategies**

| | Short term | Medium term | Long term |
|---|---|---|---|
| Domestication and cultivation | Ensure that culture practices do not threaten wild stock. | Promote and support the cultivation programs for NTFPs in order to reduce pressure on wild populations. | Support cultivation for ex-situ conservation and trading in order to reduce pressure and demand on wild population. |
| | Promote and support organic farming, integrated farming systems, and environmentally friendly agricultural systems. | Regulation of agricultural chemicals around honey bee habitats. | Encourage and promote the plantation of selected NTFP tree species in reforestation programs at community, national, and regional levels. |
| | | Prevent genetic erosion by ensuring that there is no cultivated rice in the proximity of the known populations of wild rice. | |

### 7.6.7 RESEARCH AND MONITORING

**Adaptation of NTFPs and CWRs will need additional scientific research into the basic biology and ecology of the plants and animals concerned**. There is a shortage and often a complete absence of information that can be used to assess the vulnerabilities of many species, the likely impacts, and the ways in which they may adapt to changes in climate. For many of the species concerned the typical habitat and climate requirements are still unknown, and this information is essential in planning adaptation strategies.

Populations of key plants and animals need to be monitored to record changes and responses to climate change. The rates of disease or pest infestation may change as a result of climate change, and these ecological linkages should be explored.

Monitoring may also help to identify stocks of plants that appear to have greater resilience to heat stress or drought, for example. The provinces where these are likely to be highest, e.g., in Mondulkiri, would be a good location to investigate resilience. More resilient stocks can then be used in restocking in the same or other locations (Table 46).

Table 46: Phasing of NTFP and CWR research and monitoring strategies

| | Short term | Medium term | Long term |
|---|---|---|---|
| Research and monitoring | Research to identify and protect "specific habitats" of selected species. | Monitor selected samples of NTFP populations to observe changes in productivity, disease, or insect infestation with climate change, e.g., higher temperatures. | Research on ecological characteristics of selected NTFPs and specific habitats and climate tolerances. |
| | Where there appears to be increased vulnerability, monitor individuals for signs of increased heat stress and lack of water at critical times of year, e.g., during flowering. | Expansion of NTFPs that could become invasive species should be monitored and kept in check (e.g., *Typha*). | In Mondulkiri, research to identify varieties of NTFPs that appear to be more resilient to temperature for possible transplanting. |
| | | Research into migration patterns and stopover points for honeybees. | Monitor the effects of increasing temperature on the productivity and survival of NTFPs. |
| | | Inventory and research on wild rice habitats, presence/absence, and ecological requirements. | |

### 7.6.8 SELECTION OF RESILIENCE WITHIN SPECIES

**Selective breeding of individuals that show resilience traits to the changes in climatic conditions will become an important adaptation strategy for species that are in the process of domestication**. Research and monitoring will need to provide information for the longer-term development of resilience within species. A variation of this strategy would be to consider the different species or sub-species within the same genus that occur in different parts of the LMB and consider transplanting a more resilient species to prepare for increasing temperatures in relevant parts of the LMB (Table 47).

Table 47: Phasing of NTFP and CWR selective breeding strategies

| | Short term | Medium term | Long term |
|---|---|---|---|
| Selection of resilience within species | | Identify individual plants in Mondulkiri that appear to have resilient traits against increased temperatures and water stress, and take root stocks/seeds to develop in nurseries. | |
| | | If there are signs of morbidity, lowered productivity, or reduced fertility:<br>• Actively transplant to higher elevations<br>• Consider bringing in stock from plants in provinces exposed to higher temperatures | |
| | | Consider replacement of species or sub-species with others that thrive at the predicted temperature and water availability ranges. | |

### 7.6.9 ASSISTED MOVEMENT OF SPECIES AND HABITAT

**Assisted habitat shift and movement of species at risk is a long-term adaptation strategy for important NTFP habitats.** The natural evolution of habitat in an area depends on the success and failure of the seeds of various plant species that are transported there. If the conditions are right the seeds will germinate and the plant will become successful along with others that form the ecological assemblage that defines a habitat. With climate change it is likely that the plants that characterize the habitat are not able to adapt at the same rate as the climatic conditions are changing, and the habitat will shift, becoming less stable ecologically, with some species dying out and others benefitting.

**The natural approach to facilitating habitat shift is to provide the forest with "buffer zones" in which to move as the climate changes.** The existing forest areas should not be confined artificially. Part of the problems facing protected areas is that development occurs right up to the boundary leaving no space for the evolving habitats to shift or follow shifting climatic conditions. Buffer zones around protected areas need to be established to allow for this shift. Clear biodiversity corridors are needed to allow the movement of both plants and animals to re-establish themselves in more favorable conditions.

**The assisted shift of habitat through transplanting species that appear to have greater resilience to new climate conditions, especially in forests that have been degraded will be needed in the long term.** It would be ecologically undesirable to attempt this with good quality and relatively intact forests—these should be allowed to adapt on their own. However, where the forests have been degraded and rehabilitation is necessary, a modified framework species approach could be considered, looking ahead to future climatic conditions. Forests that are growing in similar conditions, with similar soils and hydrology, could be identified, seeds of framework species collected, and seedlings grown and transplanted into the new location.

**Table 48: Phasing of NTFP and CWR assisted movement strategies**

| | Short term | Medium term | Long term |
|---|---|---|---|
| Assisted movement of species at risk and shift of habitat | | Establish the "buffer zone" for existing forest areas in order to allow natural shift of forest distribution under future climate change. | Select favorable locations e.g., where ground water is likely to remain available and use these areas for cultivation. |
| | | Plan sluice gates together with the coastal dyke to allow saline water to move in and out of the coastal dyke to provide habitat for mangroves to migrate inland. | Consider bringing in stock from plants in other provinces already exposed to higher temperatures. |
| | | | Where the threat to NTFPs is highest, consider replanting at higher elevations, with more resilient stock, or accept that some NTFPs may disappear. |

## 7.7 NATURAL SYSTEMS – PROTECTED AREAS

Protected areas have a vital role in the adaptation of farming ecosystems to climate change for the species they support and the services they project. The prior section points to the importance of NTFPs and CWRs to local communities, and to protected areas as the last resort for most. The IPCC (2007) estimates that approximately 20% to 30% of Earth's plant and animal species are likely to be at increased risk of extinction if increases in global average temperatures exceed 1.5 °C to 2.5°C. This study has shown that much of the LMB will exceed that threshold by 2050. The synergistic effects of climate change with habitat fragmentation and destruction through development can only make matters worse for species and for their habitats.

Large and rapid transformations and simplification of biodiversity in the LMB is likely within and outside protected areas due to the impacts of climate change along with other threats. That transformation will tend to reduce productivity in all farming ecosystems in the LMB with the poorest communities being most affected. Protected areas provide the backbone for adaptation in LMB agriculture, fisheries, livestock, and natural systems—and consequently for rural livelihoods. Concerted action is needed to expand and safeguard the regional protected area estate so it is able to continue fulfilling those essential support and servicing functions.

Changes are inevitable. Some species and habitats will be lost from local areas, ecozones, or from the greater LMB. Others will shift from current locations to another. The structure and composition of ecosystems in some areas will change over time and require adaptation responses from protected area managers and farmers. But the aim needs to be the enhancement and maintenance of the functions and values of the LMB protected area system as a whole. The four national governments must lead in meeting this imperative for basin-wide adaptation through better management of protected areas. But regional initiative and facilitation is needed as well, especially from government-led organizations such as the MRC, which should act as a catalyst for action to prime ministerial summit level.

This study conducted vulnerability assessments and desk-based adaptation planning for eight protected area sites and clusters in the hotspot provinces. It drew from that work and a review of protected area experiences throughout the LMB to distill key adaptation strategies by cluster, ecozone, and basin (as described in the theme volume on protected areas). Many of the basin-wide priorities for adaptation through protected areas and biodiversity conservation have been identified in the earlier sections of this report. Here those strategies are distilled into a number of imperatives for adaptation in the basin.[58]

### 7.7.1 EXPAND AND STRENGTHEN THE LMB PROTECTED AREA SYSTEM

**Expand and strengthen the protected area system to protect the full diversity of LMB habitats and increase opportunities for dispersal across the landscape:** Protecting more habitats is one of the most effective ways to maintain viable populations of a wide range of species. Building a diverse protected area system of habitats is critical in the face of climate change. Actions to strengthen and expand the LMB protected area network to adequately conserve and represent all habitats and species is an essential strategy. It will require a better foundation of scientific knowledge on the gaps and condition of the current protected area system.

### 7.7.2 BUILD ON AND STRENGTHEN EXISTING CONSERVATION APPROACHES

**Build on and strengthen existing conservation management approaches that are likely to continue to be important under climate change:** Any of the good guides and manuals to effective protected areas management from organizations such as IUCN, WWF, TNC, CI and Bird Life International identifies many of the key measure required for adaptation. Much of what is required is better and more proactive conservation management to meet what is termed in this study as *the adaptation deficit*. After much support in the 1990s, protected areas and biodiversity conservation have been neglected by most donors who could not see substantial community development and poverty-reduction benefits from their investments. Now there is a fresh and pressing need for increased and well-coordinated support to LMB protected areas as an essential

[58] A valuable source of biodiversity and protected areas adaptation options and approaches was the NSW Department of Environment, Climate Change and Water NSW, 2010, Priorities for Biodiversity Adaptation to Climate Change, http://www.environment.nsw.gov.au/resources/biodiversity/10771prioritiesbioadaptcc.pdf

adaptation strategy. Some adjustments and new emphasis and approaches will be needed. These will include high-level political commitment and more pro-active interventions.

### 7.7.3 IMPROVE UNDERSTANDING OF CLIMATE CHANGE IMPACTS ON BIODIVERSITY

**Greater attention and focus of resources is needed to improve scientific understanding of climate change impacts on species and ecosystems:** Effective adaptation strategies need to be informed by up-to-date scientific evidence. Research and monitoring is needed to understand which species and ecosystems are most sensitive to climate changes and to distinguish climate change effects from those caused by other threats. Key areas of research and monitoring relate to:

- rates of ecological change, including early warnings of key changes in ecological processes
- types of ecological change, such as in situ changes in species abundance, changes in interactions between species, and distributional shifts
- patterns of geographic range shifts over elevational and latitudinal gradients
- changes in other threats to biodiversity and their interactions with climate change
- detection of new invasive species at sites and changes in abundance and dynamics of species that may become problematic in the future, and
- effectiveness of management actions



### 7.7.4 REDUCE OTHER THREATS TO BIODIVERSITY

Protected areas in the LMB are frequently regarded by sectors and local government as reserved spaces waiting for development. Development promoted and permitted within protected areas is diminishing their primary function—the conservation of biodiversity—and regional resilience to climate change. Significantly greater political commitments are needed to safeguarding protected areas from degrading developments and influences. That requires a greater understanding in leaders of the importance of protected areas as a development and adaptation strategy if properly managed and conserved. It requires building political will and vision to take a precautionary approach and when needed to override the existing pace and scale of development that is continuing without knowledge of what is being lost. One critical innovation required in all LMB countries is strengthening the authority and capacity of protected area managers, which will be discussed below.

### 7.7.5 STRENGTHEN THE AUTHORITY AND CAPACITY OF PROTECTED AREA MANAGERS

**The highest priority for protected area adaptation in the LMB is the strengthening of capacities and processes for management planning—and for the effective implementation of a plan.** Many protected areas throughout the basin do not have management plans. There are three closely linked principles which need to be embraced in protected area legislation and strongly enforced at national and provincial levels. First is the principle of "one area one plan" so that the protected area management plan has authority over and is respected by all sectors and their development plans. Second is the principle of "one area one authority", which ensures that the protected area managers are the recognized authority within their tenured territory and that they have a mandate respected across government. Realizing the second principle will require significant institutional reform in all four LMB countries to raise the status of protected area managers within government. Stand-alone protected area legislation and statutory authorities need to be considered. Third is the principle of "one area and one management objective". That objective must be biodiversity conservation. The pursuit of two or more management objectives of equal status—such as conservation and poverty reduction—has led to failure and disillusionment over protected areas as a critical development strategy in the region. A protected area can have important poverty reduction roles through varying intensities of use in different zones—but the overriding goal of biodiversity protection and enhancement must be met.

### 7.7.6 INTEGRATED ADAPTATION IN PROTECTED AREA MANAGEMENT PLANNING

**Climate change adaptation planning and strategies need to be a fundamental part of overall protected area management planning.** The priority for protected area adaptation strategies is the reinforcement of conservation measures currently being planned and implemented in the LMB, and additional resources and attention to new measures. A lack of management plans and inadequate implementation of existing plans is a major constraint to climate change response. Protected area management planning requires support and strengthening with a precise and clear principle goal of biodiversity conservation. All other aims and uses need to be subsidiary to that peak function of protected areas. A lack of precision in the primary management goal and confusion between goals when more than one is given equal footing has led to confusion and failure to sustain effective responses to any of them. Meeting that primary goal will enable protected areas to meet their subsidiary functions, including underpinning adaptation in farming systems.

### 7.7.7 BUILDING FUNCTIONAL CONNECTIVITY ACROSS THE LANDSCAPE

**Maintaining connectivity involves establishing linkages between habitats to enable the movement of plants and animals, and to provide the supports that allow them to function.** With climate changes, corridors of natural systems need to be available for organisms to move and relocate from one protected area to another. Creating corridors for adaptation is one of the most difficult but most important strategies facing the LMB countries in the decades to come. They only work if they link together healthy protected areas.

Building and maintaining corridors to link protected areas requires extensive and long-term commitment to rehabilitation work. The local expressions of rehabilitation vary between ecosystems and habitats. Typically, rehabilitation brings back or creates ecological, social, and economic benefits provided by protected areas. Strengthening these services necessarily increases their resistance to climate change impacts.

Options for delivering corridors and rehabilitation were consider in the earlier section on NTFPs and CWRs. They include rehabilitation of degraded areas, enrichment planting and breeding programs for some threatened or critical species.

### 7.7.8 BUILDING ECOSYSTEM RESILIENCE

The resilience of an ecosystem is "the magnitude of disturbance that can be absorbed ... before variables and processes that control its behavior change and move into another stability domain" (Stolton 2010). There are clear links between ecosystem health and climate change: higher levels of biodiversity provide more options for existing processes to adapt and, therefore, offer greater climate change resilience. Actions that maintain or expand natural biodiversity are crucial components to adaptation strategies. These are management options that address the adaptation deficit—they are conservation priorities in their own right—that have become more important for their role in responding to climate change.

They involve understanding the maintenance requirements of key biological processes giving priority to keystone species that play an important role in maintaining ecological processes such as dispersal. "Keystone" species have a disproportionately large influence on community and ecosystem function relative to their numbers or biomass. Also, actions are needed for identification, maintenance, and proactive management of refugia and pockets of resilience, e.g., sites that provide microhabitats that are moister and cooler than the surrounding environment such as deep valleys in hilly terrain, drought refugia with reliable surface or groundwater and wetlands that persist during severe droughts, and areas sheltered from fire such as rocky outcrops.

### 7.7.9 ADAPTATION PLANNING FOR ECOZONES

The study identified the five priority adaptation strategies for each ecozone based on the adaptation planning for the eight protected area clusters and sites. Already many of these actions are standard conservation management requirements and responses to existing threats. They appear in management plans for protected areas that have them. They are identified as essential elements in adaptation plans for protected areas that fall within those zones following the principle of building on existing conservation approaches, which are likely to continue to be important under climate change.

Detailed adaptation strategies and their phasing for the eight protected area clusters and for ecozones are provided in the theme report on protected areas.



## 7.8 SOCIO-ECONOMICS (HEALTH AND INFRASTRUCTURE)

The study has identified an extensive range of health and infrastructure adaptation options for hotspot provinces and livelihood zones in the LMB.[59] This section provides an overview, beginning with central focus areas for adaptation in each sector. These critical areas address the four major issues identified in the CAM vulnerability assessment: (i) water-borne and vector-borne disease, (ii) maternal and child health, (iii) roads, and (iv) water supply infrastructure.

Following the overview of focus areas, detailed strategies for adaptation in particular livelihood zones of the LMB are identified. Some of these strategies are also applicable throughout the entire basin. Others will only be applicable in specific circumstances. Strategies that target rural communities are emphasized.

### 7.8.1 ADAPTION IN THE HUMAN HEALTH SECTOR

Adaptation measures in the health sector include those that reduce exposure to events and those that mitigate the full impacts after those events occur. Four adaptation strategies address the focus areas of water-borne and vector-borne disease, and maternal and child health.

**Addressing the adaptation deficit in the health sector.** Particularly important to maternal and child health is the continuing lack of adequate health access for many poor households and/or remote communities. Addressing this lack of personnel, equipment, and affordability is the starting point for adaption in the health sector. Gaps in capacity to deal with current climate and social conditions are referred to as the adaptation deficit. Addressing the adaptation deficit means that many current development priorities in the health sector (e.g., health personnel training, immunization programs, institutional capacity programs, and budgetary support) need to be supported and extended as a response to climate change.

[59] The adaptation strategies identified drew from WHO/WMO (2012), Portier et al. (2012), World Bank (2011a, 2011b, 2011c), Costello et al. (2009), McMichael et al. (2006), Sterrett (2011), Bapna et al. (2009), IPCC (2012), Douven et al. (2009), Committee on Climate Change and U.S. Transportation (2008), ADB (2011) as well as from the experience and expert judgments of the study team. The three most appropriate options were assigned to each climate threat that was assessed as high or very high for each livelihood zone of each province. Potential adaptation options were collated across province and livelihood zones. Between three and five options were selected for each livelihood zone that is the most significant in terms of their potential to enhance resilience.

**Warning, prevention, and response systems for vector-borne and water-borne disease.** There are three key factors that limit the spread of water-borne and vector-borne disease associated with extreme rainfall: *prior knowledge* (e.g., weather forecasts) that enables communities and government agencies to take precautionary measures that reduce risk (e.g., store water and food, establish shelter locations, prepare response systems, stockpile medicines, etc.); *education and other prevention measures* that mitigate damage (e.g., education regarding water-borne disease and/or use of safer water sources); and, *efficient deployment of response systems* to identify and address the spread of disease (e.g., site monitoring in affected areas, and operation of refuges and emergency health centers). Strengthening the capacity of LMB governments and non-government agencies to prepare for and respond to current frequent flooding events will be an important first step in adapting to more extreme events with climate change.

**Incorporating climate change into the design, technology, and location of health-related infrastructure**. A critical concern in an extreme event health emergency is damage to key resources such as water supply and sanitation infrastructure, health facilities, and major access roads. Failed functioning of this supporting infrastructure magnifies and extends the health emergency, particularly the spread of disease. Design standards and siting decisions should be shaped by a practical understanding of projected climate change and by zoning safeguards which promote resilient development.

**Protection of ecosystem services that support community health**. NTFPs, fisheries, and clean freshwater supply are central components of rural livelihoods. During emergency situations, such as crop failures and flood events, access to these services or stores of them are critical to food security and health, and in responding to threats to maternal and child health. The LMB's rural ecosystem services are under threat by development throughout the region and their degradation raises community vulnerability by reducing community health and welfare.

### 7.8.2 ADAPTATION IN RURAL INFRASTRUCTURE

Adaptation for rural infrastructure aims to strengthen its capacity to withstand extreme events, to avoid their impacts in the first place, or to readily recover from them. Two types of infrastructure were identified as particularly vulnerable to climate change: roads and water supply infrastructure (i.e., irrigation and drinking water infrastructure). Addressing these issues are three major focus areas for adaptation:

**Implementation of community-based bioengineering projects.** Key threats to roads and water supply infrastructure are flooding, flash floods, and landslides. In many parts of the LMB major contributors to such events are land-clearing and land degradation. Forested land absorbs surface moisture and strengthens soil stability, particularly important on sloping land. An efficient adaption response to adaption in rural infrastructure is bioengineering (Box 2).

**Box 2: Bioengineering**

*Bioengineering* refers to the use of vegetation and landscaping to improve the stability of slopes and shorelines that are susceptible to erosion and inundation. This activity is usually conducted in the interests of protecting key infrastructure (such as roads) and land, as well as preventing flooding or inundation. Bioengineering is often a low-cost alternative to major structural works (such as concrete embankments) and is also more adaptable to changed conditions. Examples of bioengineering projects include: stabilization of roads and river banks in Northern provinces of Vietnam (ICEM 2013b); re-vegetation of hillslopes along roads in Nepal (World Bank 2012); and, mangrove planting in coastal regions of the Mekong Delta (GIZ 2013). A participatory approach to implementation involving local communities increases the chances of such projects being sustainable. The use of local knowledge, labor, and materials increases the stake that communities have in maintaining the benefits of a project, as well as increasing the social costs of engaging in activities that undermine it (e.g., land-clearing).



**Revision or implementation of design standards to incorporate climate change.** Design standards for infrastructure should be upgraded to reflect future climate. Existing road and water infrastructure may require upgrades, or new climate change-resilient infrastructure may be required.

**Adaptation infrastructure.** Roads and water supply infrastructure should be located where their exposure to climate threats is minimized and special infrastructure to reduce climate change impacts should be identified, e.g., increasing the number of raised road access points to a community in a flood-prone sub-catchment, identifying necessary extensions to irrigation networks, and identifying alternative water sources to submerged groundwater bores.

Most of the proposed adaptation strategies that follow for each livelihood zone satisfy more than one of these four priorities for health and three for infrastructure.

### 7.8.3 DELTA

**Strengthen natural coastal protection from inundation through community-based rehabilitation and protection programs, particularly for mangrove ecosystems**. Degradation of mangrove ecosystems is a major factor in the exposure of coastal zone livelihoods to climate change. The continuing viability of farming, aquaculture, and NTFPs, as well as the integrity of infrastructure and human health are all contingent on protection of the low-elevation deltaic land and ecosystems from storms and the more intense flooding identified in climate change projections. Some current responses to inundation threats may in the longer term constitute maladaptation; for example, the construction of sea dykes may prevent a natural recession of mangroves and effectively exasperate coastal erosion. A current AusAID/GIZ coastal rehabilitation and climate change project located in the Kien Giang Biosphere Reserve (AusAID 2013) should produce valuable guidance on needed site-specific actions and the opportunities for their replication across the Mekong Delta.

Despite the importance of protection, the costs involved may eventually outweigh the benefits. IPCC (2007) points out that a staged and managed retreat of infrastructure and communities from the coast may, in some cases, be a more efficient allocation of resources. This is an important consideration and any decision should be informed by scientific research and monitoring, as well as economic analysis of the trade-offs involved.

**Improvements to canal networks that are required to cope with more intense flood events, particularly to ensure effective drainage of fields and waterways**. The low drainage capacity of the *Delta*'s dense system of canals and other waterways has been a significant factor in the duration and depth of major flood events. Failure of individual infrastructure, such as embankments and dykes, may have serious impacts elsewhere due to the interconnected nature of the system. The strength of the entire flood protection network was not designed with climate change in mind. A system-wide process of auditing, planning, and management is required. A Netherlands-Vietnam project (2011–2013) has developed a Mekong Delta Plan (Vietnam-Netherlands Cooperation 2011) that considered these issues.

**Support the dissemination of household infrastructure that reduces the exposure of communities to water-borne disease during flood events, such as raised rainwater tanks, floating toilets, and solar water filters.** Lack of clean water is a major cause of water-borne disease during flood events as groundwater sources are no longer available and/or contaminated. Raised rainwater tanks in strategic locations, particularly difficult to reach areas, would provide a critical emergency source of water. The first domestically produced floating toilets in the delta were recently introduced (Saigon Times 2012) and similar technology has also been deployed in Cambodia. Poor access to sanitation is a major health issue even outside of flood events; development of local supply chains to disseminate such technology would also address the adaptation deficit. In recent years, a Lao PDR company (Sunlabob 2013) and a Swiss agency (Helvetas 2013) has been involved in separate solar water disinfection projects within the LMB that could be upscaled throughout the delta region with greater research and investment.



### 7.8.4 FORESTED UPLANDS

**Strengthen sustainable management of forest resources by developing stronger land tenure systems, enhancing capacity of protected area management, and providing communities with incentives to protect forests.** Forests are a critical source of food and other forest products that sustain livelihoods, particularly in emergency situations where crops and other food supplies may be damaged or inaccessible. Governments and international non-government organizations (such as WWF, Forests and Fauna International, and Birdlife International) are involved in partnerships in various parts of the LMB to strengthen protected area management. Examples include: the Mondulkiri Protected Area cluster in Mondulkiri, Cambodia (WWF 2013), Nam Et-Phou Louey National Protected Area in Lao PDR (WCS 2013), and Kien Giang Biosphere Reserve, Vietnam (AusAid 2013). Despite such initiatives, protected areas are being degraded rapidly. A renewed level of basin-wide investment is required to expand and properly conserve these areas and the services they provide.

Forests are also important for protecting watersheds, reducing erosion and soil loss, and reducing the risk of flash flooding in upland areas. Payments to communities and local governments to protect forested areas (i.e., payments for ecosystem services, or PES) are slowly developing in the LMB. For example, there are five such watershed protection programs in Vietnam and Thailand combined (Bennett et al. 2013) and Vietnam in particular has introduced a PES policy and pilots and is working to establish the policy conditions for extensive deployment of the REDD+ mechanism (Xuan et al. 2012). These projects are in their infancy and further pilot projects and wider dissemination are needed.

**Improve road access to remote communities, including extension of the road network, construction of embankments and bridges, and community based bioengineering projects.** Communities in *Forested uplands* are the poorest and most isolated in the LMB. Improving the durability of road access to these communities would facilitate the provision of relief following extreme events and, more importantly, access to markets, health care, and livelihood opportunities year round. Community-based road user groups are needed for building and maintenance of rural roads emphasizing bioengineering methods that are designed, managed, and resourced locally. In addition to providing direct and sustainable benefits to the communities who use these resources, external financial incentives for such activities would inject further resources into communities and thereby reduce poverty and climate change vulnerability.

**Improve access to maternal and pediatric healthcare, including child immunization programs and access to trained health professionals for pre- and post-natal care.** Maternal and infant mortality rates in *Forested uplands* of the LMB are very high. This is a high priority in addressing the adaptation deficit. Climate change is projected to increase the prevalence of conditions conducive to the spread of vector-borne disease, such as malaria and dengue fever, and water-borne disease. Children and recent mothers are particularly susceptible to such diseases. If they are further weakened due to poor maternal and pediatric healthcare, then the health-related impacts of climate change would be amplified.

### 7.8.5 INTENSIVELY-USED UPLANDS



**Reforestation and other locally-managed bioengineering initiatives in riparian and sloping areas, especially those linked to strategic rural infrastructure.** Such programs could include community-based incentives schemes to strengthen slope stability on erosion-prone slopes, for example, through arrangements for PES.

Large areas of *Intensively-used uplands* across the LMB are vulnerable to climate change due to landuse practices, particularly deforestation to expand agricultural land in riparian and sloping areas. Programs to strengthen the stability of land and reduce erosion will protect the productivity of land and reduce the risk of death and injury from flash floods and landslides. Well-designed and sustainable incentive-based schemes at the community level are needed. The lessons from such a scheme in China, the Sloping Land Conversion Program (see Konig et al. 2012 and Bennett 2008) are applicable to the LMB as well as Vietnam's recent experiences in regulation and piloting of PES in this livelihood zone.

**Climate-sensitive design, siting, and maintenance of major infrastructure in areas highly vulnerable to extreme events.** Population density and incomes in *Intensively-used uplands* are relatively high compared to *Forested uplands*. The capacity for governments to meet demand for additional infrastructure is likely to rise over time and it is critical that any new investments in roads, bridges, and culverts and associated drainage systems incorporate future climate change in project design. That will require taking watershed approaches to road design and considering land management issues outside the normal road corridor.

The location or relocation of strategic infrastructure, such as health facilities and major roadlinks, away from vulnerable areas is a primary consideration. Further afield, the impact of the 2010 Pakistan floods was greatly exacerbated by the destruction of 39 major health facilities (WHO 2010). When such infrastructure is incapacitated or destroyed through poor siting, the impact of the extreme event on isolated communities is magnified.

### 7.8.6 LOWLAND PLAINS AND PLATEAUS

**Improve access to safe water and sanitation, including covered groundwater bores, rainwater tanks, water treatment technology, and covered latrines.** *Lowland plains and plateaus* areas may be subject to drought, flooding, and other events that restrict access to safe drinking water. In many remote areas of Lao PDR and Cambodia, surface water from rivers and lakes is a commonly used water source. Poor sanitation facilities increase the risk of contamination and the spread of water-borne disease, particularly during floods. Increasing access to safe water and sanitation outside of extreme weather events is an important adaptation deficit strategy, as is strengthening the resilience of the infrastructure to extreme weather events.

**Construction of heat-respite community centers for the benefit of vulnerable groups.** The young, elderly, and sick are highly exposed to illness and death resulting from heat stress. Many areas of the *Lowland plains and plateaus* are projected to experience increases in maximum temperature. A common practice in some countries is to provide air-conditioned heat respite centers for exposed groups. Although this may not be an efficient strategy in all circumstances and would require supporting transportation infrastructure, particularly in areas with highly dispersed populations, it should be considered in areas where temperature rise is projected to be extreme and population density is sufficiently high. One option in off-grid areas would be the installation of air-conditioners powered by rooftop solar panels.

**Enhance food security and flood protection by strengthening sustainable management of forest and river resources.** This strategy would include developing stronger land tenure systems and enhancing capacity of protected area management. Encroachment of agricultural land on forest areas as a result of informal land tenure, partly driven by migration towards dwindling natural resources, is a major cause of unsustainable use of forested lands. Illegal deforestation and other illegal activities in protected areas where sustainable use is permitted degrade forest resources and their availability to surrounding communities. Unsustainable fishing practices and the impacts of upstream developments reduce the availability of fish and the viability of other resources. Watershed protection in particular will reduce the threat posed by flooding; community-based bioengineering projects using local resources offer a sustainable pathway to strengthening already degraded riparian areas.

### 7.8.7 FLOODPLAIN

**Climate change-sensitive bridge and culvert construction, road elevation and design, and other civil engineering programs to secure road access to flood-prone communities.** Communities in floodplain areas are highly exposed to isolation during flood events. Ensuring the security of road access will reduce the vulnerability to subsequent food and water insecurity, disease epidemics, and raise the overall adaptive capacity.

**Community-managed bioengineering programs in riparian areas.** Bioengineering is a cost-efficient form of watershed protection in riparian areas and the lack of natural infrastructure to provide flood protection is a central component of the adaptation deficit in the *Floodplain* zone. Pilot incentive schemes in favorable areas will provide the information necessary to upscale sustainable afforestation and reforestation activities throughout this livelihood zone.

**Strengthen institutional capacity for provision of forecasting, early warning systems, and effective response for flooding and water-borne and vector-borne disease.** The provision of information prior to flood events and on conditions for vector-borne disease will allow households to take preventative action that will reduce their exposure, such as moving assets to higher ground and the inoculation or destruction of livestock (in the case of zoonoses—or diseases transferred from animals to humans). The extension of mobile phone networks to remote areas may be a critical component of this strategy.

A preventative strategy for reducing the spread of water- and vector-borne disease is the capacity to take action once the threat is present. For example, early knowledge that one community is affected by vector-borne disease may allow preventive measures, such as quarantine, which may limit the spread to neighboring communities. The UNDP Disaster Risk Management program in three provinces of the Mekong Delta has engaged in an integrated fashion and provides lessons for

*Floodplain* zones of the LMB (see UNDP 2011). A particularly prominent feature of this program is the development of centralized disaster risk management centers at the provincial level that provide improved capacity for cross-sectoral coordination.

## 7.9 INTEGRATED ADAPTATION

The importance of integrated adaptation planning and implementation is a key theme of this report. In practice it is complex and difficult to achieve because it involves action and incentives at many levels and across all arms of government.

**Integrating policies:** The directions and mechanisms for achieving integration need to be spelled-out in *integrating policies at national level*—i.e., in strategies, plans, and laws—which are to be reflected in provincial policy frameworks—for example, requiring integrated river basin plans to be prepared and providing for their effective implementation.

**Integrating structures:** There are *integrating structures* that need to be established along with the incentives for making them work – for example, there is no point in setting up an intersectoral committee or working group on climate change adaptation or integrated planning for a river basin if the sector staff involved do not have lateral working relations and sharing emphasized in duty statements or in performance evaluation systems.

**Integrating procedures:** Then there are *integrating procedures and tools*—the most widely used and accepted being the environment impact assessment (EIA). The EIA system in all LMB countries requires ongoing strengthening—after much attention in the late 1990s, it has been relatively neglected as a tool for internationally-supported capacity building and its integrating force remains poorly developed. Strategic environmental assessment has been promoted and important SEAs conducted, which have considered climate change threats and adaptation requirements such as those on hydropower development on the mainstream Mekong River and on the Vu Gia – Thu Bon catchment in Quang Nam Province, Vietnam (ICEM 2007 and 2012)—but SEAs are a long way from becoming an integrating force for adaptation systematically applied in the LMB.

One critical tool and process for integration is spatial planning. It is one of the three key points which emerge from this adaptation chapter when the imperative for integrated adaptation is considered.

**Spatial planning as the foundation for adaptation at site level:** Adaption may involve actions at policy or procedural level; and it may involve education and awareness raising. But when concerned with specific interventions on site, adaptation is best planned and achieved on an "area wide" basis that facilitates understanding of the importance of integration across sectors and levels of government. The opportunities for adaptation and integration become clearer when considered for specific geographic areas. Even adaptation planning for organizations such as line ministries whose activities are expressed locally need to consider how their mandates and responses to climate change play out on the ground. In a spatial planning approach to adaptation it is possible to define zones and linked safeguards/guidance as the backdrop for adaptation and development.

Area-wide adaptation plans are a first step and provide the impetus for different sectors to integrate climate change into their own plans, and to consider the linkages to other sectors in devising a response.

**Recognize the trade-offs involved between sectors when preparing area-wide adaptation plans.** The critical trade-offs become evident when taking an integrated approach; they are less obvious when focusing on only one sector—which is most often the case. As the IPCC points out:

"There are also important trade-offs in adaptation. For instance, while hard protection can greatly reduce the impacts of sea level and climate change on socio-economic systems, this is to the detriment of associated natural ecosystems due to coastal squeeze. Managed retreat is an alternative response, but at what cost to socio-economic systems? General principles that can guide decision making in this regard are only beginning to be developed." [60]

In this study, a potential adaptation option identified for areas where rainfed rice is subject to more extreme flooding and increased dry season rainfall is a shift to a dry season irrigated crop. However, the irrigation water may be coming from wetlands that support aquatic NTFPs and livestock. Diverting water for irrigation in the dry season may undermine these other components of community livelihoods. Structures and tools are needed for recognizing and resolving conflicts and trade-offs of this kind in the adaptation planning process. Those processes and the difficult decisions that government and communities will need to make need to be guided by adaption principles set out in the opening to this chapter. A number of tools have been introduced to facilitate the identification of trade-offs and consensus building—two are *adaptation impact assessment* to assess the likely cross-sector impacts of a proposed adaptation measure and *adaptation audits* which reviewed what happened once the adaptation measure was implemented (ICEM 2012).

**Seek out complementarity approaches available across sectors**. While it may not always be the case that "win-win" solutions are available, they should be prioritized where they are identified. The reasons are because complementary approaches (i) are more efficient in the use of resources, (ii) are likely to be mutually reinforcing and to generate sustainable adaptation, and (iii) are likely to be supported by a wider range of stakeholders. A prominent example of a cross-sector sustainable adaptation strategy promoted in this study is the preservation of natural forest resources. The complementary benefits are numerous: flood protection for agriculture, habitat preservation for fisheries, protection of NTFPs, supply of forage for livestock during price rises in commercial fodder, and so on. Only through an integrated, area-wide planning process will the full scope of such complementary adaptation opportunities be realized.



[60] IPCC, 2007, Fourth Assessment Report: Climate Change 2007, Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability, http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch6s6-6-3.html

# 8 BIBLIOGRAPHY AND REFERENCES



## Agriculture

Africare, Oxfam America, WWF-ICRISAT Project. 2010. *More Rice for People, More Water for the Planet.* WWF-ICRISAT Project, Hyderabad, India.

AIT UNEP. 2011. *Practitioners ad Policy-makers Exchange on Climate Change Adaptation in Agriculture. Frequently asked questions Booklet.* 30 pp.

Ayers, R.S. and Westcot D.W. 1985. *Water quality for agriculture.* FAO. Irrigation and drainage PAD 29. Rev. 1. FAO. Rome.

Belfield, S. and C. Brown. 2009. *A guide to upland cropping in Cambodia: Maize.* ACIAR Monograph. 54 pp.

Belfield, S., C. Brown, and R. Martin. 2011. *Soybean, a guide to upland cropping in Cambodia.* ACIAR Monograph. 76 pp.

Brown, L. 2005. China replacing the United States as world's leading consumer. Washington DC, USA: Earth Policy Institute. http://www.earthpolicy.org/Updates/Update45.htm.

Carew-Reid, J. 2007. *Rapid assessment of the extent and impact of sea level rise in Viet Nam. Climate Change Discussion Paper 1.* ICEM – International Centre for Environmental Management, Hanoi, Vietnam.

CGIAR-CSI. 2006. *LUSET – Land Use Evaluation Tool.* Available at: http://csi.cgiar.org/CGIARGeoSpatialTools.asp#LUSET.

CGIAR. 2007. *Adapting Agricultural Systems to Climate Change, Global Climate Change: Can Agriculture Cope?* Consultative Group on International Agricultural Research (CGIAR), Research and Impact: CGIAR and Climate Change, available at www.cgiar.org/impact/global/.

Chinavanno, S. 2004. *Building capacity of Mekong River countries to assess impacts from climate change-case study approach on assessment of community vulnerability and adaptation to impact of climate change on water resources and food production.* Final Report of APN CAPaBLE Project. Southeast Asia START Regional Centre.

Chinvanno, S. Snidvongs, A. (eds.). 2005. *The Study of Future Climate Changes Impact on Water Resource and Rain-fed Agriculture Production.* Proceedings of the APN CAPaBLE CB-01 Synthesis Workshop, Vientiane, Lao PDR, 29–30 July 2004. SEA START RC Technical Report No. 13, 113 pp.

Corsi, S., Friedrich T., Kassam A., Pisante M., and de MoraesSa J. 2012. *Soil Organic Carbon accumulation and greenhouse gas emission reductions for conservation agriculture: A literature review.* FAO Rome, 103 pp.

Cruz, R.V.; Harasawa, H.; Lal, M.; Wu, S.; Anokhin, Y.; Punsalmaa, B.; Honda, Y.; Jafari, M.; Li, C.; HuuNinh, N. 2007. Asia. In: *Climate change 2007: Impacts, adaptation and vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. Parry, M.L.; Canziani,O.F.; Palutikof, J.P.; van der Linden, P.J.; Hanson, C.E., 469-506. Cambridge, UK: Cambridge University Press.

Dasgupta, S.; Laplante, B.; Meisner, C.; Wheeler, D.; Yan, J. 2007. *The impact of sea-level rise on developing countries: A comparative analysis.* World Bank Policy Research Working Paper 4136. Washington, DC: World Bank.

D'Haeze, D., DEckers J., Raes D., Tran AnPhong, Nguyen Dang Minh Chanh. 2003. *Over-irrigation of Coffeacanephora in the Central Highlands of Vietnam revisited simulation of soil moisture dynamics in RhodicFerralsols.*

Doorenbos, J., Kassam, A.H. 1979. *Yield Response to Water.* FAO Irrigation and Drainage Paper 33, FAO, Rome.

Douangsavanh, L., B. Thammavong, and A. Noble. 2008. *Meeting Regional and Global Demands for Rubber: A Key to Poverty Alleviation in Lao PDR?* Sustainable Mekong Research Network (Sumernet).

Eastham, J., Mpelasoka F., Mainuddin M., Ticehurst C., Dyce P., Hodgson G., Ali R. and Kirby M. 2008. *Mekong River Basin water resources assessment: impacts of climate change.* CSIRO: Water for a Healthy Country National Research Flagship.

Eastburn, DM, Degennaro MM, Delucia EH, Dermody O, Mcelrone AJ. 2010. *Elevated atmospheric carbon dioxide and ozone alter soybean diseases at SoyFACE.* GlobalChange Biology 16: 320–330.

Ecocrop 2012. *http://ecocrop.fao.org/ecocrop/srv/en/home.*

*FiA Strategic Planning Framework 2010–2019 (2010),* Fisheries Administration (FiA), MAFF. FAO. 2008. Regional Data Exchange System on food and agricultural statistics in Asian and Pacific countries maintained by the FAO Regional Office for the Asia Pacific Region *(http://www.faorap-apcas.org).*

FAOSTAT. 2012. *http://faostat.fao.org/DesktopDefault.aspx?PageID=339&lang=en&country=216.*

FAO. 2008. *Project Summary Report Phase I.* Improved Adaptive Capacity to Climate Change for Sustainable Livelihoods in the Agriculture Sector, Community Based Adaptation in Action: A case study from Bangladesh.

Frenck, G., van der Linden L., Mikkelsen TN, Brix H., and Jorgensen RB. 2011. *Increased $CO_2$ does not compensate for negative effect on yield caused by higher temperature and O3 in Brassica napus L.* European Journal of Agronomy 35:127–134.

General Statistic Office of Vietnam. 2012. *http://www.gso.gov.vn/default_en.aspx?tabid=491.*

Groeningen van KJ, Kessel van C, Hungate B.A. 2012. *Increased greenhouse-gas intensity of rice production under future atmospheric conditions.* Nature Climate Change DOI: 10.1038/NCLIMATE1712.

Haggar, J., and Schepp K. 2011. *Coffee and climate change.* Desk study: Impact of climate change in four pilot countries of the coffee & climate initiative. University of Greenwich. 78 pp.

Hasegawa, T., Kuwagata T, Nishimori M, Ishigooka Y, Murakami M, Yoshimoto M, KondoM, Ishimaru T, Sawan S, Masaki Y, Matsuzaki H. 2009. *Recent warming trends and rice growth and yield in Japan.* MARCO Symposium on Crop Production under Heat Stress: Monitoring, Impact Assessment and Adaptation. National Institute for Agro-Environmental Studies, Tsukuba, Japan.

Herrera, B., Hyman G, Belloti A. 2011. *Threats to cassava production: Known and potentialgeographic distribution of four key biotic constraints.* Food Security 3 (3), 329–345.

Hicks, C., S Weiyi, G Zhong, L. Sun. 2009. *Rubber investments and market linkages in Lao PDR: approaches for sustainability.* The Sustainable Mekong Research Network. 160 pp.

Hoanh, C.T., T.P. Tuongb, K.M. Gallop, J.W. Gowing, S.P. Kam, N.T. Khiem and N.D. Phong. 2003. *Livelihood impacts of water policy changes: evidence from a coastal area of the Mekong river delta.* Water Policy 5. 475–488.

Hoanh, C.T., Guttman, H., Droogers, P., Aerts, J. 2003. ADAPT. *Water, Climate, Food and Environment under Climate Change. The Mekong basin in Southeast Asia.* International Water Management Institute, Mekong River Commission, Future Water, Institute of Environmental Studies. Colombo, Phnom-Penh, Wageningen.

Hoanh, C.T.; Guttman, H.; Droogers, P.; Aerts, J. 2004. *Will we produce sufficient food under climate change?* Mekong Basin (South East Asia). Chapter 8. In: Climate change in contrasting river basins: Adaptation strategiesfor water, food and environment, ed. Aerts, J.; Droogers, P. UK: CABI.

Hortle, K.G. 2007. *Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin. MRC Technical Paper No. 16*. Mekong River Commission, Vientiane. 88 pp.

Howie, C. A. 2011. *Co-operation and contestation: farmer-state relations in agricultural transformation, An Giang Province, Vietnam.* PhD Thesis. London: Royal Holloway, University of London [Available at http://digirep.rhul.ac.uk/items/a91241e4-38f9-705a-a8ca-74f026413dd1/1/, accessed 30/04/11].

Husson, O.; E. Colliot, M.T. Phung. 1996. *Le développement rural de la Plaine des Joncs.* Agriculture et développement 9 ; 51–61.

IFDC. 2011. *Fertilizer Deep Placement (FDP)*. *http://ifdc.org/getdoc/81fcf68e-c3b8-406a-a252-5148b99d8684/Fertilizer_Deep_Placement_(UDP)* accessed 20/08/2012.

International Water Management Institute (IWMI). 2007. *A Comprehensive Assessment of Water Management in Agriculture.*

IWMI. 2009. *Economic gains of improving soil fertility and water holding capacity with clay application: the impact of soil remediation research in Northeast Thailand.*

Jaggard, KW, Qi A, Ober ES. 2010. *Possible changes to arable cropyields by 2050.* Philisophical Transaction of the Royal Society 365:2835-2851.

Joffre, O.M., & Bosma R.H. 2009. *Typology of shrimp farming in Bac Lieu Province, Mekong Delta, using multivariate statistics.* Agriculture, Ecosystems and Environment.132, 153–159.

Joffre, O., and Sheriff N. 2011. *Conditions for collective action: understanding factors supporting and constraining community-based fish culture in Bangladesh, Cambodia and Vietnam.* Studies and Reviews 2011-21. The WorldFish Center, Penang, Malaysia. 43p.

Johnston, R.; Hoanh, Chu Thai; Lacombe, G.; Noble, A.; Smakhtin, V.; Suhardiman, D.; Kam, SuanPheng; Choo, PohSze. 2009. *Scoping study on natural resources and climate change in Southeast Asia with a focus on agriculture.* Report prepared for the Swedish International Development Cooperation Agency by International Water Management Institute, Southeast Asia (IWMI-SEA). Vientiane, Lao PDR: International Water Management Institute, South East Asia Office (IWMI-SEA). 118 p. doi: 10.3910/2010.201).

Johnston, R. M.; Hoanh, C. T.; Lacombe, G.; Lefroy, R.; Pavelic, P.; Fry, C. 2012. *Improving water use in rainfed agriculture in the Greater Mekong Subregion.Summary report.* Colombo, Sri Lanka: International Water Management Institute (IWMI); Stockholm, Sweden: Swedish International Development Cooperation Agency (Sida). 44p. doi:10.5337/2012.200.

Kakonen M. 2008. *Mekong Delta at the crossroads: More control or adaptation?* Ambio 37(3):205- 212.

Kono, Y., Tomita, S., Nagata, Y., Iwama, K., Nawata, E., Junthotai, K., Katawatin, R., Kyuma, K., Miyagawa, S., Niren, T., Noichana, C., Sakuratani, T., Sributta, A., Watanabe, K. 2001. *A GIS-based crop-modeling approach to evaluating the productivity of rainfed lowland paddy in North-east Thailand.* In. Fukai, S. and Basnayake, J. (ed.), Increased Lowland Rice Production in the Mekong Region. ACIAR Proceedings 101, Canberra.

Krishnan, P., Swain, D.K., Bhaskar, B.C., Nayak, S.K., Dash, R.N. 2007. *Impact of elevated $CO_2$ and temperature on rice yield and methods of adaptation as evaluated by crop simulation studies.* Agriculture, Ecosystems and Environment 122, 233–242.

Ladha, J. K., Fisher K. S. Hossain M., Hobbs P. R. And Hardy B., Editors. 2000. *Improving the Productivity and Sustainability of Rice-Wheat systems of the Indo-Gangetic plains: A synthesis of NARS-IRRI Partnership Research.* Discussion Paper 40, International Rice Research Institute.

Lao Statistic Bureau. 2012. http://www.nsc.gov.la/.

Le Coq, J.-F., Trébuil, G., &Dufumier, M. 2004. *History of rice production in the Mekong Delta.* In : Smallholders and stockbreeders. Histories of food crop and livestock farming in Southeast Asia. L. KITLV: 163–185.

Lefroy, R., Collet L., Grovermann, C. 2010. *Study on Potential Impacts of Climate Change on Land Use in the Lao PDR Potential impacts of climate change on land use in the Lao PDR.* Report prepared for GiZ. 90 pp.

Leakey ADB, Ainsworth EA, Bernacchi CJ, Rogers A, Long SP, Ort DR. 2009. *Elevated $CO_2$ effects on plant carbon, nitrogen, and water relations: six important lessons from FACE.* Journal of Experimental Botany 60(10): 2859–76. doi:10.1093/jxb/erp096.

Lobell, DB, Bänziger M, Magorokosho C, Vivek B. 2011. *Nonlinear heat effects on African maize as evidenced by historical yield trials.* Nature Climate Change 1: 42–45.

Lobell, DB, and Field C. 2008. *Estimation of the carbon dioxide (Co2) fertilization effect using growth rate anomalies of Co2 and crop yield since 1961.* Global Change Biology 14: 39–45.

Long, SP, Ainsworht EA, Leakey ADB, Nosberger J, Ort DR. 2006. *Food for thought: lower than expected crop yield simulation with rising $CO_2$ concentration.* Science 312: 1918–1921.

MAFF (Ministry of Agriculture, Forestry and Fisheries). 2009a. *Economic land concession in Cambodia.* Cambodia: Ministry of Agriculture, Forestry and Fisheries. http://www.elc.maff.gov.kh/.

MAFF. 2011. Ministry of Agriculture, forestry and Fisheries in Cambodia. *2011Statistics.*

Mainuddin, M., and M. Kirby. 2009. *Spatial and temporal trends of water productivity in the lower Mekong River Basin.* Agricultural Water Management 96: 1567–1578.

Mainuddin, M., Hoanh, C.T., Jirayoot, K., Halls, A.S., Kirby, M., Lacombe, G., Srinetr, V. 2010. *Adaptation options to reduce the vulnerability of Mekong water resources, food security and the environment to impacts of development and climate change.* CSIRO: Water for a Healthy CountryNational Research Flagship. 152 pp.

Marsh, A. 2007. *Diversification by Smallholder Farmers: Viet Nam Robusta Coffee*. FAO.

McElwee, P. 2010. *The Social Dimensions of Adaptation to Climate Change in Vietnam.* Discussion paper No. 12. The World Bank, Washington, DC.

Morgan, PB, Bollero GA, Nelson RL, Dohleman FG, Long SP. 2005. *Smaller than predicted increase in aboveground net primary production and yield of field-grown soybean under fully open-air [$CO_2$] elevation.* Global Change Biology 11: 1856–1865.

MPI (Ministry of Planning and Investment). 2008. *Approved foreign investment by country and sector 2001–January 2008 in Lao PDR.* Vientiane, Lao PDR: Government of Lao PDR.

MRC. 2010. *State of the Basin Report 2010.* Vientiane, Lao PDR: Mekong River Commission.

NAFRI. 2011. Improved pastures and DMC-based upland rice cultivation: Two solutions to intensify land-use in Pek district. Policy Brief. 2011.

Palada, M., Bhattarai S.P., Roberts M., Baxter N., Bhattarai M., Kan S., and DL Wu. 2010. *Increasing on-farm water productivity through farmer-participatory evaluation of affordable microirrigation vegetable-based technology in Cambodia.* Journal of applied irrigation science. Vol. 45, no. 2, 133–143 pp.

Pillot, Didier. 2007. *JardinsetRizieres du Cambodge.* Paris: GRET-Karthala.

Peng, SB, Huang JL, Sheehy JE, Laza RC, Visperas RM, Zhong XH, Centeno GS, Khush GS, Cassman KG. 2004. *Rice yields decline with higher night temperature from global warming.* Proceedings of the National Academy of Sciences 101: 9971–9975.

Ponlock, T. 2010. *Climate change: causes, impacts and adaptation in agriculture and water resources.* Presentation at the Inception Workshop for Launching "Promoting Climate-Resilient Water management and Agricultural practices in Rural Cambodia" 20 January 2010, Phnom Penh, Cambodia.

Resurreccion, BP, Sajor EE, and Fajber E. 2008. *Climate Adaptation in Asia: Knowledge Gaps and Research Issues in South East Asia.* A Full Report of the South East Asia Team, Climate Change Adaptation Southeast Asia, ISET-International and ISET-Nepal.

RCG. 2004. *The Rectangular Strategy for Growth, Employment, Equity and Efficiency in Cambodia.*

Roberts, M., and A Long. 2006. *Drip Irrigation Trial in Prey Veng and Svay Rieng 2005–2006.* IDE Report. 19 pp.

Roth, C., Dalgliesh N and Grunbuhel C. 2012. *ACIAR Trip Report.* 36 pp.

Roy, R. N., and Misra R. V. 2003. *Economic and environmental impact of improved nitrogen management in Asian rice-farming systems in Sustainable rice production for food security.* Proceedings of the 20th Session of the International Rice Commission, Bangkok, Thailand, 23-26 July 2002 International Rice Commission, FAO, Rome.

Ruosteenoja, K., Carter, T. R., Jylhä, K., Tuomenvirta, H. 2003. *Future climate in world regions: an intercomparison of model-based projections for the new IPCC emissions scenarios.* Finnish Environment Institute. Helsinki. 81 pp.

Rutherford, J.; Lazarus, K.; Kelley, S. 2008. *Rethinking investments in natural resources: China's emerging role in the Mekong region.* Phnom Penh, Cambodia: Heinrich BollStiftung, WWF and International Institute for Sustainable Development.

Sheehy, J.E., Mitchell, P.L., Ferrer, A.B. 2006. *Decline in rice grain yields with temperature: Models and correlations can give different estimates.* Field Crops Res. 98, 151–156.

Snidvongs, A., Choowaew, S. and Chinvanno, S. 2003. *Impact of climate change on water and wetland resources in Mekong river basin: directions for preparedness and action.* IUCN (The World Conservation Union) and Southeast Asia START Regional Center. Bangkok. 54 pp.

Someth P., N. Kubo, H. Tanji, S. Ly. 2009. *Ring dike system to harness floodwater from the Mekong River for paddy rice cultivation in the Tonle Sap Lake floodplain in Cambodia.* Agricultural Water Management 96: 100-110.

Sys, Ir. C., E. Van Ranst, J. Debaveye and F. Beernaert. 1993. *Land Evaluation Part III - Crop requirement.* Belgium General Administration for Development Cooperation.Agricultural Publications No. 7.

Tacio, H.D. 1993. *Sloping Agricultural Land Technology (SALT): a sustainable agroforestry scheme for the uplands.* Agro-forestry Systems 22, 145–152**.**

Thivet, F., Chantharath B, Tran Quoc H. Julien P, Leinarhd P, Panyasiri K, Seguy L. Shiting. 2008. *Cultivation and Poverty irrigation in the Uplands of the Lao PDR.* NAFRI Workshop proceedings: 375–388.

TKK & SEA START RC. 2009. *Water and Climate Change in the Lower Mekong Basin: Diagnosis & recommendations for adaptation.* Water and Development Research Group, Helsinki University of Technology (TKK), and Southeast Asia START Regional Center (SEA START RC), Chulalongkorn University. Espoo, Finland: Water & Development Publications, Helsinki University of Technology. 55 pp.

Tuong, T.P., Kam S.P, Hoanh C.T, Dung L.C., Khiem N.T., Barr J. & Ben D.C. 2003. *Impact of seawater intrusion control on the environment, land use and household incomes in a coastal area.* PaddyWater Environment1, 65–73.

Tuong, T.P., Minh, L.Q., Ni, D.V. & van Mensvoort, M.E.F. 1998. *Reducing acid pollution from reclaimed acid sulphate soils: Experiences from the Mekong Delta, Vietnam.* In: Water and the Environment: Innovative Issues in Irrigation and Drainage. (Pereira, L.S. &Gowing, J.W. (eds.)), 75–83 pp. E&FN Spon, Routledge, London.

UNDP. 2011. *Climate change and Agriculture.* Cambodia Human Development Report 2011. 9 pp.

Valentin, C.; Agus F.; Alamban, R.; Boosaner, A.; Bricquet, J.P.; Chaplot, V.; de Guzman, T.; de Rouw, A.; Janeau, J.L.; Orange, D.; Phachomphonh, K.; Phai Do; Podwojewski P.; Ribolzi. O.; Silvera, N.; Subagyono, K.; Thiébaux, J.; Toan, T.; Vadari, T. 2008. *Runoff and sediment losses from 27 upland catchments in Southeast Asia: Impact of rapid land use changes and conservation practices.* Agriculture, Ecosystems and Environment 128: 225–238.

Vo, L.T.T. 2003. *Quality management in shrimp supply chain in the Mekong Delta, Vietnam: problems and measures.* Centre for ASEAN Studies, Antwerp Belgium. Discussion Paper Series 43, 28 pp.

Wasmann, R., N.X. Hien; C.T. Hoanh; T.P. Tuong. 2004. *Sea Level Rise affecting the Vietnamese Mekong Delta: water elevation in the flood season and implication for rice production.* Climatic Change 66: 89–107.

Voladet, S. 2008. *Sustainable development in the plantation industry in Lao PDR: An examination of the role of the Ministry of Planning and Investment.* Winnipeg, Canada: International Institute for Sustainable Development, 34 p.

Welch, JR; Vincent, JR; Auffhammer, M; Moyae, PF; Dobermann, A; Dawe, D. 2010. *Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures.* Proceedings of the National Academy of Sciences 107: 14562–14567.

WFP. 2008. *Comprehensive Food Security and Vulnerability Analysis.* Kingdom of Cambodia. 103 pp.

World Bank. 2011. *Economic Adaptation to Climate Change.* Vietnam. Washington DC. 84 pp.

Yasuyuki, K., O. Hisaya, E. Nawata and T. Shinsuke. 2004. *Aspects of Shifting Cultivation in Northern Laos: Land Allocation Policy and Commercialization of Crop Production.* In: Ecological Destruction Health and Development. Advancing Asian Paradigms. Kyoto Area Studies on Asia. 637 pp.

Yen, B.T., Pheng, K.S. and Hoanh, C.T.  2006. *LUSET User's guide.* International Rice Research Institute: 15 p.

Yoshida, S. 1981. *Fundamental Science of Rice Crop*. IRRI, Los Banos, Philippines. 269 pp.

Zou, J., Liu AL, Chen XB, Zhou XY, Gao GF, Wang WF, Zhang XW. 2009. *Expression analysis of nine rice heat shock protein genes under abiotic stresses and ABA treatment.* Journal of Plant Physiology 166(8): 851–861.

## Aquaculture and capture fisheries

Akataweewat, S. 2004. *Knowledge of Freshwater Fish in Thailand, Volume 1*. Khurusapha (the Council of Teachers), Bangkok. 264 pp. (in Thai).

Akataweewat, S. 2003. *Public Manual for Identification of aquatic Food safety.* Fisheries Technology Transfer and Development Bureau. Department of Fisheries. Bangkok. 164 pp. (in Thai).

Alison, A.H, Beveridge M.C.M, van Brakel M.L. 2012. *Climate Change, small-scale fisheries and smallholder aquaculture.* Fisheries Sustainability and Development.

Baran, E., Makin I, Baird I.G. 2003. *Bayfish: a model of environment factors driving fish production in the Lower Mekong Basin.* Contribution to the Second International Symposium on Large Rivers fro Fisheries. Phnom Peng, Cambodia, 11-14 February 2003.

Baran, E., Saray Samadee, Teoh Shwu Jiau, Tran Thanh Cong. 2011. *Fish and fisheries in the Sesan River Basin - Catchment baseline, fisheries section.* Project report. Mekong Challenge Program project MK3 "Optimizing the management of a cascade of reservoirs at the catchment level". WorldFish Center, Phnom Penh, Cambodia. 61 pp.

Baran, E. and Mith S; *Fish biodiversity along the Mekong. From the Himalaya to the Coast.* Power point presentation.
http://www.jsps.go.jp/english/eastrategy/date/07_asiahorcs_03_p1/keynote/keynote5_%20Baran.pdf.

Baren, E., and E. Guerin. 2012. *PP Presentation River sediments and coastal fish production: what about the mekong?* Project "A Climate Resilient Mekong: Maintaining the Flows that Nourish Life" led by the Natural Heritage Institute and funded by USAID.

Bonheur, N. 2001. *Tonle Sap Ecosystem and Value.* Technical Coordination Unit for Tonel Sap, Ministry of Environment, Phnom Penh, Cambodia.

Boonyaratpalin, M., K. Kohanantakul, B. Sricharoendham, T. Chittapalpong, A.Termvitchagorn, W.Thongpun and M. Kakkaew. 2002.  *Ecology, Fish Biology and Fisheries in the Lower Songkhram River Basin.* Technical Paper no. 6/2545. Department of Fisheries. Bangkok. (in Thai).

Chan, S., Putrea S. and H.G. Hortle. 2005. *Using local knowledge to inventory deep pools, important fish habitats in Cambodia.* In Proceedings of the 6 Technical Symposium on Mekong Fisheries (6 Technical Symposium on Mekong Fisheries, Pakse, Lao PDR, 26th-28th November 2003). T.J. Burnhill and M.M. Hewitt, eds. Mekong River Commission. Vientiane. 57–76 pp.

Chea, V., and Sean Kin. 2000. *Fisheries Preservation in the Mekong River Pools in Stung Treng and Kratie Provinces.* Presentation at the 2nd Mekong River Commission Fisheries Programme technical symposium. Phnom Penh. 13-14 December 1999. 6 pp.

Chinvanno, S. 2008. *Information for sustainable development in light of climate change in Mekong River Basin.* Part II Remote Sensing and Geographic Infrmation Systems (GIS) Applications for sustainable development.

Chunsawang, B., T. Poompipat, P. Sodsook, S.Tanusutuch and P. Kaewjarune. 2000. *Survey on Fish Population in Chulaporn Reservoir.* Chaiyapoom province. Technical Paper No. 122. Inland Fisheries Research Institute. Bangkok. (in Thai).

Deap, L., P Degen and N. van Zalinge. 2003. *Fishing Gears of the Cambodian Mekong.* Inland Fisheries Research and Development Institute of Cambodia, (IFReDI), Phnom Penh. Cambodia Fisheries Technical Paper Series Volume IV (2003). 269 pp. ISSN: 17263972.

Degen, P., Piseth C., Swift P. and Mary H. 2005. *Upland Fishing and Indigenous Punong fisheries management in southern Mondulkiri Province, Cambodia.* Report for W

De Graaf, G.J. & N.D. Chinh1. 2008. *Floodplain Fisheries in the Southern Provinces of Vietnam.*

Department of Fisheries. 2003. *Survey and design of Kwan Phayao for restoration project and public hearing.* Final Report. Kasetsart University. Bangkok. (in Thai).

Department of Fisheries. 1983. *Tilapia (Pla Nil) Technical Paper no. 17.* Department of Fisheries. Bangkok. (in Thai).

Department of Fisheries. 2011. *Manual for Good Aquaculture Practice.* Improvement of Standard Farm of Tilapia Culture for Export Project. Ministry of Agriculture and Cooperatives. 32 pp. (in Thai).

Duangsawat, M., and S. Duangsawat. 1992. *Fishery Resources and Status in Mun River.* Technical Paper no. 136. Department of Fisheries. Bangkok. (in Thai).

Duangsawat, S., and T. Chukajorn. 2000. *Fishery Status, Species and Distribution in Mun River.* Technical Paper no. 125. Department of Fisheries. Bangkok. (in Thai).

Duangsawat, S., Y. Leenanon, B. Sricharoendham and D. Ruttanachumnong. 1994. *Fishery Resources and Status in Nonghan Reservoir after Restoration Programme.* Technical Paper no. 158. Department of Fisheries. Bangkok. (in Thai).

Duangsawat, S., B. Sricharoendham, P. Kaewjarune, M. Aimsub, W. Somchun and N. Promkrun. 2003. *Ecology and Fish Population in Nonghan, Sakonnakorn Province.* Technical Paper no. 6. Department of Fisheries. Bangkok. (in Thai).

Duangsawat, S. 1993. *Survey on Fish Species and Abundance in Pakmun Dam.* Technical Paper no. 152. Department of Fisheries. (in Thai).

Eastham, J., F. Mpelasoka, M. Mainuddin, C.Ticehurst, P. Dyce, G. Hodgson, R. Ali, and M. Kirby. 2008. *Mekong River Basin Water Resources Assessment: Impacts of Climate Change.* CSIRO: Water for a Healthy Country National Research Flagship.

Edwards, P., Le Anh Tuan and Allan, G.L. 2004. *A survey of marine trash fish and fish meal as aquaculture feed ingredients in Vietnam.* ACIAR Working Paper No. 57.

FAO. 2008. *Climate Change for Fisheries and Aquaculture.* Technical background document from the expert consultation held on 7 to 9 April 2008, FAO Rome.

FAO Fisheries Country Profile, (Lao PDR), http://www.fao.org/fishery/countrysector/FI-CP_LA/en.

FAO RAP. 2001: Niklas S. MATTSON Wolf D. HARTMANN Thomas AUGUSTINUS MRC Fisheries Programme Vientiane, Lao PDR Reservoir Fisheries Information: From Statistics to Management in New Approaches for the Improvement of Inland Capture Fishery Statistics in the Mekong Basin.

Ficke, AD, Myrick CA, Hansen LJ. 2007. *Potential impacts of global climate change on freshwater fisheries.* Rev Fish Biol Fisheries (2007) 17: 581–613.

Fisheries Research and Development Bureau. 2003. *Regulations and Standard for Giant Freshwater Prawn Culture 2003.* Department of Fisheries. Bangkok. 102 pp. (in Thai).

Fisheries Technology Transfer and Development Bureau. n.d. *Public Manual for Aquaculture.* Department of Fisheries. Bangkok. 44 pp. (in Thai).

Fisheries Technology Transfer and Development Bureau. 2006. *Common Fishes for Aquaculture.* Department of Fisheries. Bangkok. 64 pp. (in Thai).

Fisheries Technology Transfer and Development Bureau. 2005. *Guideline for Snakeskin Gourami Culture.* Department of Fisheries. Bangkok. 36 pp. (in Thai).

Fisheries Technology Transfer and Development Bureau. 1993. *Guideline for Brackish Water Fish Culture.* Department of Fisheries. Bangkok. 48 pp. (in Thai).

Fisheries Technology Transfer and Development Bureau. 2010. *Guideline for Tilapia Culture.* Department of Fisheries. Bangkok. 34 pp. (in Thai).

Fisheries Technology Transfer and Development Bureau. 2006. *Guideline for Striped Catfish Culture.* Department of Fisheries. Bangkok. 24 pp. (in Thai).

Gregory, R., Guttman, H., and T. Kekputherith. 1996. *Poor in All But Fish.* A Study of the Collection of Ricefield Foods from Three Villages in Svay Theap District, Svay Rieng. Working Paper No. 5. 1–27. AIT Aqua-Outreach Programme, Phnom Penh, Cambodia.

Gregory, R.G. 1997. *Ricefield Fisheries Handbook.* Cambodia-IRRI-Australia Project, Cambodia. 38 pp.

Hill, M.T. 1995. *Fisheries ecology of the Lower Mekong River: Myanmar to Tonle Sap River.* National Historical Bulletin, Siam Society. 43263-288.

Hortle, K.G. 2007. *Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin.* MRC Technical Paper No. 16, Mekong River Commission, Vientiane. 87 pp.

Hortle, K.G., Troeung R., and S. Lieng. 2008. *Yield and value of the wild fishery of rice fi elds in Battambang Province, near the Tonle Sap Lake, Cambodia.* MRC Technical Paper No.18. Mekong River Commission, Vientiane. 62 pp.

Hortle, K.G., S. Lieng and J. Valbo-Jorgensen. 2004. *An introduction to Cambodia's inland fisheries.* Mekong Development Series No. 4. Mekong River Commission, Phnom Penh, Cambodia. 41 pp. ISSN 1680-4023.

ICEM. 2010. *Strategic Environmental Assessment (SEA) of hydropower on the Mekong mainstream.* Prepared for the Mekong River Commission, Vientian, Lao PDR.

Jangkij, M., J. Dumrongtripob, N. Sriputanipol and N. Sukumasavin. 2004. *Ecology and Fishery Resources in Pong Chi and Mun Rivers.* Technical Paper no 30. Roi-et Fishery Research and Development Center. Roi-Et. (in Thai).

Johnston, R.; Hoanh, Chu Thai; Lacombe, G.; Noble, A.; Smakhtin, V.; Suhardiman, D.; Kam, Suan Pheng; Choo, Poh Sze. 2009. *Scoping study on natural resources and climate change in Southeast Asia with a focus on agriculture.* Report prepared for the Swedish International Development Cooperation Agency by International Water Management Institute, Southeast Asia (IWMI-SEA). Vientiane, Lao PDR: International Water Management Institute, South East Asia Office (IWMI-SEA). 118 pp. doi: 10.3910/2010.201.

Kam, S.P., Badjeck M-C, Teh L., Teh L., Bé Năm V.T, Hiền T.T, Huệ _N.T, Phillips M., Pomeroy R. , Sinh L.X. 2010. *Economics of adaptation to climate change in Vietnam's aquaculture sector: A case study.* Report to the World Bank.

Kaw-anantakul, K., C. Vidthayanon, A. termvidchakorn, C. Sirikul and N. Junprathad. 2003. *Fishes of the Bueng Borapet Swamp (Lower Chao Phraya basin).* Inland Fisheries Research and Development Bureau. Department of Fisheries. Bangkok.84 pp. (in Thai).

Kottelat, Maurice, Ian G. Baird, Sven O. Kullander, Heok Hee Ng, Lynne R. Parenti, Walter J. Rainboth & Chavalit Vidthayanon. 2012. *The status and distribution of freshwater fishes of Indo-Burma.* 36-65 pp. in Allen, D.J., Smith, K.G., and Darwall, W.R.T. (Compilers). The Status and Distribution of Freshwater Biodiversity in Indo-Burma. IUCN, Cambridge, UK and Gland, Switzerland.

Lamberts, D. 2001. *Tonle Sap fisheries: a case study on floodplain gillnet fisheries in Siem Reap, Cambodia.* FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. RAP Publication 2001/11, 133 pp.

LARReC. 2001. *A report on cage culture in Lao PDR.* LARReC Research Report 0002. ISSN 1608 5604.

Limsuwan, C. 1992. *Manual for Black Tiger Shrimp Culture.* Tansettakij Limited Company. Bangkok. (in Thai).

Marod, D., Watcharinrat, C., Duengkae, P., and Jenkitkan, S. 2004. Draft Final Report on Implementation of the Ramsar Convention in Thailand: Management and Protection of Wetland Areas (Phase 2: Nong Bong Khai ecological study).

Mattson, N. S., Balavong, V., Nilsson, H., Phounsavath, S. and Hartmann W.D. 2001. *Changes in Fisheries Yield and Catch Composition at the Nam Ngum Reservoir, Lao PDR.* In: De Silva, S.S. (Ed.), Reservoir and Culture-Based Fisheries: Biology and Management, pp 48-55. Proceedings of an International Workshop held in Bangkok, Thailand 15-18 February 2000. ACIAR Proceedings No. 98. Australian Center for International Agricultural Research, Canberra, Australia.

Meynell, P.J. 2012. *Assessing the Ecologocal Significance of the Mekong Tributaries.*

Meynell, P.J. 2003. *Scoping Study for Biodiversity Assessment of the Mekong River in Northern Laos and Thailand.* IUCN Mekong Water and Nature Initiative and Mekong Wetlands Biodiversity Conservation and Sustainable Use Programme, Bangkok.

MRC 2010. *State of the Basin Report.* 2010. Mekong River Commission, Vientiane, Lao PDR. ISBN 978-993-2080-57-1. 2010 Mekong River Commission.

MRC. 2002. *Fish migrations of the Lower Mekong River Basin: implications for development, planning and environmental managament.* MRC Technical Paper No 8.

MRC. 2009. *Adaptation to climate change in the countries of the Lower Mekong Basin*. MRC Management Information Booklet Series No.1.

MRC. 2010. *MRCSEA Assessment report Fisheries Baseline assessment.* Working Paper.

Phan, Minh Thu & J, Populus. 2007. *Status and changes of mangrove forest in Mekong Delta: Case study in Tra Vinh, Vietnam.* Estuarine, Coastal and Shelf Science 71 (2007). 98–109 pp.

Prommanon, P. and S. Sahawatcharin. 1968. *Experiment of Giant Freshwater Prawn Culture in Cement Tank.* Songkla Fisheries Station Annual Report. Department of Fisheires. (in Thai).

Pongsuwan, A. and A. Sittimung. 1989. *Manual for Fish Culture in the Northeast.* Department of Fisheries. (in Thai).

Poulsen, A. F., Ouch Poeu, Sintavong Viravong, Ubolratana Suntornratana, & Nguyen Thanh Tung. 2002. *Fish migrations of the Lower Mekong Basin: implications for development, planning and environmental management.* MRC Technical Paper No 8. Mekong River Commission, Phnom Penh. 62 pp. ISSN: 1683-1489.

Poulsen, Anders, Ouch Poeu, Sintavong Viravong, Ubolratana Suntornratana & Nguyen Thanh Tung. 2002. *Deep pools as dry season fish habitats in the Mekong Basin.* MRC Technical Paper No. 4. Mekong River Commission, Phnom Penh. 22 pp. ISSN: 1683-1489.

Rainboth, W.J. *FAO species identification field guide for fishery purposes.* Fisheries of the Cambodian Mekong. Rome FAO. 1996. 265p., 27 colour plates.

Rainboth, W.J. 1996. *Fishes of the Cambodian Mekong.* FAO, Rome.

SDC Report. 2007, unpublished. *Upland Aquatic Resources in Lao PDR.Their Use, Management & Spatial Dimensions in Xieng Khouang & Luang Prabang Provinces.*

SDC Report. 2007, unpublished. *An assessment of the importance of riparian ecosystems as generators of agro-biodiversity resources at a gradient of elevations and farming systems.*

Shang, U.C. and T. Fujimura. 1977. *The production economic of freshwater prawn, Macrobrachium rosenbergii.* Aquaculture 20: 251-256 pp.

Sinh, L.X. 2008. *Application of bio-economic model for improving economic efficiency and technique of giant freshwater prawn (Macrobrachium rosenbergii) hatcheries in the Mekong Delta, Vietnam.* (abstract in English). Scientific Journal of Cantho University 2,143-156 pp.

Sinthavong, Viravong, Sommano Phounsavath, Chanthone Photitay, Putrea Solyda, Chan Sokheng, J. Kolding, J. Valbo Jorgensen and Kaviphone Phoutavong. 2006. *Hydro-acoustic surveys of deep pools in Southern Lao PDR and Northern Cambodia.* MRC Technical Paper No.11, Mekong River Commission, Vientiane. 76 pp. ISSN: 1683-1489.

Smith, H.M. 1945. *The Fresh-Water Fishes of Siam, or Thailand.* United State Government Printing Office, Washington. 622 pp.

Sricharoendham, B. and K. Ko-anantakul. 1993. *Fish Catch and Fisheries Survey During the Rehablitation Program of Nong Han Swamp, Sakon Nakhon Province, 1992.* Technical Paper No. 143. Department of Fisheries. Bangkok. 36 pp. (in Thai).

Sriwattana, W. and Y. Wiwattanachaiset. n.d. *Guideline for Red tailed Catfish Culture.* Fisheries Technology Transfer and Development Bureau Department of Fisheries. Bangkok. 22 pp. (in Thai).

Sverdrup-Jensen, S. 2002. *Fisheries in the Lower Mekong Basin: Status and Perspectives.* MRC Technical Paper No. 6, Mekong River Commission, Phnom Penh. 103 pp. ISSN: 1683-1489.

Taracharanukij, W. and P. Tabtipwun. 1992. *Fishery Resources before Constructing Hauy-Laung Irrigation System.* Faculty of Fisheries. Kasetsart University. Bangkok. (in Thai).

Taracharanukij, W., P. Tabtipwun and S.Rourjai. 1992. *Fishery Resources before Constructing Lahanna Irrigation System.* Faculty of Fisheries. Kasetsart University. Bangkok. (in Thai).

Thongkum, T., V. Temiyajol, W. Thepaouichai and S. Didtabud. 1991. *Study on Situation of Fishery resources and Socio-economic in Lower Mun River.* Electricity Generating Authority of Thailand. Nonthaburi province. (in Thai).

Tiensongrudsamhee, B. 1978. *Principles for Giant Freshwater Prawn Culture.* Faculty of Fisheries, Kasetsart University 107 pp. (in Thai).

Tyson, R. Roberts and Ian G. Baird. 1995. *Traditional Fisheries and Fish Ecology on The Mekong River at*

*Rhone Waterfalls in Southern Laos.* Nat. Hist. Bull. Siam Soc. 1995. 43: 219–262.

Vidthayanon, C., Karnasuta J. and J. Nabhitabhata. 1997. *Diversity of Freshwater Fishes in Thailand.* Office of Environmental Policy and Planning. Bangkok. 102 pp. (in Thai).

Vidthayanon, C. 2008. *Field Guide to Fishes of the Mekong Delta.* Mekong River Commission, Vientiane, 288 pp.

Vidthayanon, C. 2005. *Thailand Red Data: Fishes.* Office of Natural Resources and Environmental Policy and Planning, Bangkok, Thailand. 23 pp.

Welcomme, R.L., and C. Vidthayanon. 2003. *The impacts of introductions and stocking of exotic species in the Mekong Basin and policies for their control.* MRC Technical Paper No. 9. Mekong River Commission, Phnom Penh, Cambodia. 35 pp. and annex.

Wickins, J.F. and Daniel O'C. Lee. 2002. *Crustacean Farming Ranching and Culture.* Blackwell Science Ltd, UK. 446 pp.

Wiwattanachaiset, Y. and R. Tipnate. n.d. *Guideline for Giant Freshwater Prawn Culture.* Fisheries Technology Transfer and Development Bureau. Department of Fisheries. Bangkok. 26 pp. (in Thai).

World Bank. 2010. *Vietnam: Economics of Climate Change Adaptation.*

Zalinge, N.V. P. Degen1, C. Pongsri, S. Nuov, J.G. Jensen, N.V. Hao and X. Choulamany. 2003. *The Mekong River System.* Contribution to the Second International Symposium on the Management of Large Rivers for Fisheries Phnom Penh, 11-14 February 2003. 31-1-03.

## Livestock

Asian Development Bank (ADB). 2005. *Final Report.* Participatory Livestock Development Project. ADB PPTA No. 4287 LAO: Socioeconomic Assessment.

ADB. (unknown date). *Climate Change Vulnerability, Adaptation and Mitigation in The Greater Mekong.* Sub: Greater Mekong Subregion Core Environment Program.

Asian Veterinary and Livestock Services (ASVELIS). 2011. *Documentation and Impact Analysis of Interventions in the Cattle Sub-Sector in Tuong Duong and Ky Son Districts, Nghe An Province.* For Oxfam Hong Kong, Hanoi, Vietnam.

Agrifood Consulting International. 2005. *Final Report for the Cambodian Agrarian Structure Study.*

Asian Wild Cattle Specialist Group (AWCSG). 2012. http://www.asianwildcattle.org/.

Barrett, J. 1992. *The Economic Role of Cattle in Communal Farming Systems in Zimbabwe Pastoral Development Network.* Overseas Development Institute (ODI), Paper 32b.

Chantong, W., and Kaneene, J.B. 2011. *Poultry Raising Systems and Highly Pathogenic Avian Influenza Outbreaks in Thailand: The Situation, Associations, and Impacts.* http://www.tm.mahidol.ac.th/seameo/2011-42-3/14-5089.pdf.

Cocks, P., Abila, R., Bouchot, A., Benigno, C., Morzaria, S., Inthavong, P., Long, N.V., Luthi, N.B., Scoizet, A., and Sieng, S. 2009. *FAO ADB and OIE SEAFMD Study on Cross Border movement and market chains of large ruminants and pigs in the Greater Mekong Sub Region.*

Connell, J., Stur, W., and Horne, P. 2010. *Forages and Farmers: Case Studies from South-East Asia.* ACIAR, Canberra and CIAT Vientiane. ACIAR Monograph No. 142.

Convention on Biological Diversity (CBD). 1993. http://www.cbd.int/.

Crotty, R. 1980. *The Indian Case: Cattle Grazed Communally; Milk has Value.* Cattle Economics and Development, Cabi Publishing. 163–192 pp.

CARE, Catholic Relief Services, Oxfam and PACT. 2012. *Drowning in Debt: The Impact of the 2011 Cambodia Floods on Household Debt: A Survey Of Poor Households In Three Affected Provinces.*

DIPECHO. 2011. *Reducing Multi Hazard Induced Risks and Building Community Resilience to Disaster in Cambodia: Disaster Resilient Livestock to Support the Poorest Households – Livestock Consultant's Report.* Unpublished

FAO. 2012a. *Global Livestock Production and Health Atlas (GLiPHA).* http://kids.fao.org/glipha/. Accessed 25 August 2012.

FAO. 2012b. *Technical Session I: Introduction to Flood Management.* FAO Corporate Document Repository. Rome, Italy. *http://www.fao.org/docrep/004/ac146e/AC146E01.htm*.

FAO. 2012c. *The Livestock Industries of Thailand: The Dairy Industry.* *http://www.fao.org/docrep/004/ac797e/ac797e05.htm.* Accessed 27 August 2012.

FAO. 2011a. *Mapping Supply and Demand for Animal-Source Foods to 2030*. FAO. Rome, Italy.

FAO. 2011b. *Atlas of Poultry Production in Pilot Provinces.* FAO. Hanoi, Vietnam.

FAO-AGAL. 2005a. *Livestock Sector Brief: Cambodia.* FAO. Rome, Italy.

FAO-AGAL. 2005b. *Livestock Sector Brief: Vietnam.* FAO. Rome, Italy.

FAO-AGAL. 2005c. *Livestock Sector Brief: Lao PDR.* FAO. Rome, Italy.

FAO-AGAL. 2005d. *Livestock Sector Brief: Thailand.* FAO. Rome, Italy.

FAO/WFP. 2012. *Crop and Food Security Update Mission to Cambodia*. Report. Rome.

Farooq, H., Samad, H.A., Shehzad, F. and Qayyum, A. 2010. *Physiological Responses of Cattle to Heat Stress.* World Applied Sciences Journal 8 (Special Issue of Biotechnology & Genetic Engineering): 38–43 pp.

Forman, S., Hungerford, N., Yamakawa, M., Yanase, T.,Tsai, HJ., Joo, Y.S. Yang, D.K. and Nha, J.J. 2008. *Climate change impacts and risks for animal health in Asia.* Rev. sci. tech. Off. int. Epiz. 2008, 27 (2), 581–597.

Gallen, M. 2004. *Rural Development Project Dak Lak (RDDL)*. Vietnam: Concept for Sustainable Upland Farming in Dak Lak Province. GTZ.

Hansen, P.J. 2004. *Physiological and cellular adaptations of zebu cattle to thermal stress.* Animal Reproduction Science 82–83 (2004). 349–360.

Hatfield, J.L. 2008. *The Effects of Climate Change on Livestock Production.* The Pig Site, *http://www.thepigsite.com/articles/2296/the-effects-of-climate-change-on-livestock-production*.

Huffington Post. 2011. *10,000 Cattle Dead In Vietnam: Cows, Buffalo Part of Mass Die-Off.* *http://www.huffingtonpost.com/2011/01/21/10000-cattle-dead-vietnam_n_812224.html*.

Huyen, L.T.T., Herold, P. and Valle Zárate, A. In Press 2009. *Farm types for beef production and their economic success in a mountainous province of northern Vietnam.* Agricultural Systems, Vietnam. Agr. Syst. (2009). doi:10.1016/j.agsy.2009.11.004.

Huyen, L.T.T., Herold, P. Markmann, A. and Valle Zárate, A. 2011. *Resource use, cattle performance and output patterns on different farm types in a mountainous province of northern Vietnam.* Animal Production Science 51, 650–661.

ILRI. 2012. *Mapping of Poverty and Likely Zoonoses Hotspots.* http://cgspace.cgiar.org/handle/10568/21161.

Indochina Research Ltd and Psilos, P. 2007. *The Cambodian Swine Value Chain: Market Function and Dysfunction.* Prepared for DAI for the USAID Cambodia MSME Project. Phnom Penh, Cambodia.

Informa Agra (Agra-net). 2012. *Food Supply Future: Famine of Plenty?* https://www.agra-net.com/portal2/.

IOM. 2009. *Mapping Vulnerability to Natural Hazards in Mondulkiri – Final Report.* IOM, Cambodia.

IUCN. 2012. *Red List.* http://www.iucnredlist.org/details/2888/0.

Jabbar, M.A., Baker, D. and Fadiga, M.L. 2010. *Demand for livestock products in developing countries with a focus on quality and safety attributes: Evidence from case studies.* International Livestock Research Institute (ILRI), Nairobi, Kenya.

Johnston, R. M., Hoanh, C. T., Lacombe, G., Noble, A. N., Smakhtin, V., Suhardiman, D., Kam, S. P., Choo, P. S. 2010. *Rethinking agriculture in the Greater Mekong Subregion: how to sustainably meet food needs, enhance ecosystem services and cope with climate change.* Colombo, Sri Lanka: International Water Management Institute. 26 pp. doi:10.3910/2010.207.

Kamakawa, A., Ho Thi Viet Thu, Ly Thi Lien Khai, Le Thi Thu, Yamada, R., Yamane, I., and Taniguchi, T. *Pig management in Tan Phu Thanh village and characterization of the losses.*

Khounsey, S., Nampanya, S., Inthavong, P., Yang, M., Khamboungheung, B., Avery, M., Bush, R., Rast, L., and Windsor, P.A. 2011. *Significant mortality of large ruminants due to hypothermia in northern and central Lao PDR.* Tropical Animal Health Production.

Knips, V. 2004. *Review of the Livestock Sector in the Mekong Countries.* FAO-AGAL, FAO, Rome, Italy.

Lapitan, T. M., Del Barrio, A. N., Katsube, O., Tokuda, T., Orden, E. A., Robles, A. Y., Fujihara, T., Cruz, L. C., and Kanai, Y. 2004. *Comparison of feed intake, digestibility and fattening performance of Brahman grade cattle (Bos indicus) and crossbred water buffalo (Bubalus bubalis).* Animal Science Journal (2004). 75, 549–555.

Lüthi, N. 2010. *Beef cattle and buffalo trade patterns from Xieng Khouang province, Lao PDR to Vietnam.*

Lüthi, N. 2007. *National trends in supply and demand of beef (red meat) in Vietnam with special reference to Xieng Khouang province Lao PDR.*

Lüthi, N, et al. 2007. *Rapid market appraisal on cattle and buffaloes in M'drak district, Dak Lak province.*

Luthi, N. 2010. *Beef Cattle and Buffalo Trade Patterns from Xieng Khouang Province, Lao PDR to Vietnam.*

Maclean, M. 2006. *Cattle Finishing - Technical Implementation Procedure.* ACIAR.

Mekong Wetlands Biodiversity Conservation and Sustainable Use Program (MWBC). 2005. *Vulnerability Assessment of Climate Risks in Stung Treng Province, Cambodia.* UNDP, IUCN, MRC.

Mekong Wetlands Biodiversity Conservation and Sustainable Use Programme (MWBC). 2012. http://www.mekongwetlands.org/Demonstration/Thailand/livelihoods.htm.

MRC. 2000. *Kok River Basin - Pilot Study for Water Resources and Environment Management (Basinwide): Final Report.* 7.1.25/97/UKM

MRC. 2010. *Proceedings of the 8th Annual Mekong Flood Forum Vientiane, Lao PDR.* 26–27 May 2010.

NGO Forum on Cambodia. 2005. *Down River: The Consequences of Vietnam's Se San River Dams on Life in Cambodia and Their Meaning in International Law.*

Nguyen Quang Dung. 2011. *Biogas User Survey 2010–2011: Biogas Development Program for Livestock Sector in Vietnam 2007–2012*. Hanoi, Vietnam.

OIE. 2012. SEACFMD News. OIE, Bangkok, Thailand.

Patza, J. A., Graczykb, T. K., Gellera, N., and Vittorc, A. Y. 2000. *Effects of environmental change on emerging parasitic diseases.* International Journal for Parasitology (2000).

Pen, M., Savage, D., Stür, W. and Senga, M. 2009. *Constraints to Cattle Production of Small-scale Farmers in Kampong Cham Province, Cambodia.* University of Hamburg.

Quirke, D., Jarding, M., Vincent, D. and Garrett, D. 2003. *Effects of Globalisation and Economic Development on the Asian Livestock Sector.* ACIAR. Canberra, Australia.

Renaudeau, D., Huc, E., Kerdoncuff, M. and Gourdine, J.L. 2006. *Acclimation To High Ambient Temperature In Growing Pigs: Effects Of Breed And Temperature Level.* Symposium COA/INRA Scientific Cooperation in Agriculture. Tainan (Taiwan, R.O.C.).

Rocha, A., Randel, R.D., Broussard, J.R., Lim, J.M., Blair, R.M., Roussel, J.D., Godke, R.A., Hansel, W. 1998. *High environmental temperature and humidity decrease oocyte quality in bos taurus but not in bos indicus cows.* Theriogenology. Feb; 49(3): 657-65 pp.

Shephard, A. W. 2010. *Rice Market Information in Cambodia.* IRRI, unpublished.

Simaraks, S. 1998. *Roles and Limitations of Animals in the Farming Systems in Southeast Asia: Field Observations and Experiences.* In: 'Upland Farming Systems in the Lao PDR: Problems and Opportunities for Livestock' ACIAR. Canberra, Australia.

Srikitjakarn, L., Sirimalaisuwan A, Khattiya R, Krueasukhon K, and Mekaprateep M. 2002. *Seroprevalence of melioidosis in dairy cattle in Chiang Mai Province, northern Thailand.* Southeast Asian Journal of Tropical Medicine and Public Health. Dec 33(4): 739-41 pp.

Teufel, N., Markemann, A., Kaufmann, B., Valle Zárate, A. and Otte, J. 2010. *Livestock Production Systems in South Asia and the Greater Mekong Sub-Region: A Quantitative Description of Livestock Production in Bangladesh, Cambodia, India, Lao PDR, Nepal, Pakistan, Sri Lanka, Thailand, and Viet Nam*. FAO-PPLPI. Working Paper No. 48.

Thornton, P.K., Kruska, R.L., Henninger, N., Kristjanson, P.M., Reid, R.S., Atieno, F., Odero, A.N. and Ndegwa, T. 2002. *Mapping poverty and livestock in the developing world.* ILRI. Nairobi, Kenya.

Truong Tan Khanh, Stür, W, Nguyen Van Ha and Duncan, A. 2009. *Developing Innovation capacity through effective partnerships: moving from subsistence cattle raising to market-oriented beef production in Dak lak, Vietnam.*

Truong Tan Khanh, Stür, W., Van Tien Dzung, and Nguyen Van Ha. 2010. *Assessment of cattle marketing in Ea Kar district, Daklak, Vietnam in 2008*. CIAT. Fodder Adoption Project Working Paper Series.

Tuoitre News. 2011. *7,000 Buffalo and Cows Freeze To Death in Vietnam.* http://www.sott.net/articles/show/221627-7-000-Buffalo-and-Cows-Freeze-To-Death-in-Vietnam.

Unattributed 'Field Study: Lao PDR: Nam Et and Phou Loei National Biodiversity Conservation Areas'.

VV Online. 2010. *Blue-ear Pig Disease spreads to 24 provinces and cities.* http://english.vov.vn/Home/Blueear-pig-disease-spreads-to-24-provinces-and-cities/20108/118749.vov.

World Food Program (WFP). 2012a. *Kampong Cham Provincial Food Security Profile.* http://www.foodsecurityatlas.org/khm/country/provincial-Profile/Kampong-Cham.

WFP. 2012b. *Mondulkiri Provincial Food Security Profile.* http://www.foodsecurityatlas.org/khm/country/provincial-Profile/Mondulkiri.

WFP. 2012c. *Stung Treng Provincial Food Security Profile.* http://www.foodsecurityatlas.org/khm/country/provincial-Profile/Stung-Treng.

WFP. 2012d. *Risk and Vulnerability Analysis: Lao PDR.* http://www.foodsecurityatlas.org/lao/country/vulnerability/risk-analysis.

## Climate change modeling

Choi, W., Rasmussen, P. F., Moore, A. R., and Kim, S. J. 2009. *Simulating streamflow response to climate scenarios in central Canada using a simple statistical downscaling method.* Climate Res., 40, 89–102 pp.

Chung, C., Ramanathan, V., Kim, D. and Podgorny, I. 2005. *Global anthropogenic aerosol forcing derived from satellite and ground based observations*. Journal of Geophysical Research. Volume 110.

Collier, J., and Zhang, G. 2009. *Aerosol direct forcing of the summer Indian monsoon as simulated by the NCAR CAM 3*. Climate Dynamics. 32: 313–332.

Delgado, J. M., Merz, B., and Apel, H. *A climate-flood link for the lower Mekong River.* Hydrol. Earth Syst. Sci. 16, 1533–1541.

Diaz-Nieto, J., and Wilby, R. L. 2005. *A comparison of statistical downscaling and climate change factor methods: impacts on low flows in the River Thames, United Kingdom*. Climatic Change, 69, 245–268 pp.

FAO. 2011. *Food and agricultural commodities production.* Available at http://faostat.fao.org/site/339/default.aspx.

ICEM. 2011, *Mekong delta connectivity road.* Report prepared for ADB.

Koponen, J., Lauri, H., Veijalainen, N., and Sarkkula, J. 2010. *HBV and IWRM Watershed Modelling User Guide, MRC Information and Knowledge management Programme,* DMS – Detailed Modelling Support for the MRC Project. http://www.eia.fi/index.php/support/download.

Lauri, H. 2011. *VMOD hydrological model 5km baseline calibration.* Internal document prepared by EIA Ltd.

Lauri, H. EIA Ltd. 2011. *Vmod hydrological model MKF 5km reservoir scenario.*

Nguyen K., Toan, T. 2010. *An investigation on the efficient use of water related to the upstream development scenarios to prevent drought and salinity intrusion in the Mekong delta*. National project KC08-11/06-10. Hanoi Water Resources University (HWR) & Southern Institute of Water Resources Research (SIWRR).

Huy, N., Toan, T. 2010. *Scientific base for adaptation measures for climate change and sea water level rise to the Mekong delta.* Ministry level project. Hanoi Water Resources University.

Raes, D., Stedutu, P., Hsiao, T and Fereres, E. 2009. *AquaCrop reference manual.* Published by Food and Agriculture Organization, United Nations.

Räsänen, T.A. and Kummu, M. In press. *Spatiotemporal influences of ENSO on precipitation and flood pulse in the Mekong River Basin*. Journal of Hydrology. Vol 476. 154-168 pp.

Räsänen, T.A., Lehr, C., Mellin, I., Ward, P.J. and Kummu, M. 2012. *Paleoclimatological perspective on the hydrometeorology of the Mekong Basin.* Hydrology and Earth System Sciences Discussion 9: 12729-12764.

Västilä, K., Kummu,M., Sangmanee,C. & Chinvanno,S. 2010. *Modelling climate change impacts on the flood pulse in the lower Mekong floodplains*. Journal of Water and Climate Change. 1: 67-86 pp.

Vuuren, D., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G., Kram, T., Krey, V., Lamarque, J., Masui, T., Meinsausen, M., Nakicenovic, N., Smith, S. and Rose, S. 2011. *The representative concentration pathways: an overview.* Climatic Change. 109: 5-31 pp.

Watnabe, M., Suzuki, T., O'Ishi, R., Komuro, Y., Watanabe, S., Emori, S., Takemura, T., Chikira, M., Ogura, T., Sekiguchi, M., Takata, K., Yamazaki, D., Yokohata, T., Nozawa, T., Hasumi, H., Tatebe, H. and Kimoto, M. 2010. *Improved climate simulation by MIROC5: Mean states, variability and climate sensitivity*. Journal of Climate. Vol 23. 6312–6335 pp.

Wang, B., Yang, J., Zhou, T., and Wang, B. 2008. *Inter-decadal Changes in the Major Modes of Asian-ustralian Monsoon Variability: Strengthening Relationship with ENSO since the Late 1970s**. J. Climate, 21, 1771–1789 pp.

## Natural systems – NTFPs and CWRs

Australian Tropical Forest Plant website. *http://keys.trin.org.au/key-server/data/0e0f0504-0103-430d-8004 060d07080d04/media/Html/taxon/Passiflora_foetida.htm*.

B.B, Baki, D.V.Chin, and M. Mortimer, editors. 2000. *Wild and weedy rice in rice ecosystems in Asia–A Review*. Limited Proceedings, 2000. No 2. International Rice Research Institute (IRRI). Available at: *http://paradies.agrar.hu-berlin.de/nutztier/ntoe/asia/lectures-phil/crop-prod/07/baki-2000.pdf*.

C., Mohanasundari, D. Natarajan, K. Srinivasan, S. Umamaheswari and A. Ramachandran Antibacterial properties of Passiflora foetida L. – a common exotic medicinal plant. African Journal of Biotechnology Vol. 6 (23), 2650-2653 pp. 3 December, 2007. Available online at *http://www.academicjournals.org/AJB*. ISSN 1684–5315 © 2007 Academic Journals.

Erin Harwood, and Mark Sytsma. 2003. *Risk Assessment for Chinese Water Spinach Ipomoea aquatica in Oregon*. Center for Lakes and Reservoirs Portland State University Portland, OR 97207. Available at: *http://cms.oregon.gov/OISC/docs/pdf/ipaq_ra.pdf*.

FAO, 2009, *Thailand forestry outlook study*. Asia-pacific forestry sector outlook study ii. Working paper series, Working paper no. Apfsos ii/wp/2009/22.

Hashimoto Takehiko Riko. 2001. Working Paper Series. Working Paper No 4. Environmental Issues and Recent Infrastructure Development in the Mekong Delta: review, analysis and recommendations with particular reference to large-scale water control projects and the development of coastal areas. Australian Mekong Resource Center, University of Sydney.

Ian Campbell. 2012. *Biodiversity of the Mekong Delta.* The Mekong Delta System. Springer Environmental Science and Engineering. 2012. 293–313 pp.

ICEM. 2012. *Rapid climate change assessments for wetland biodiversity in the Lower Mekong Basin.* Consultant report prepared for the Mekong River Commission, Hanoi, Viet Nam.

J.M. Suttie. Sesbania sesban (L.) Merr. FAO website. Available at: *http://www.fao.org/ag/AGP/AGPC/doc/Gbase/data/pf000170.htm*.

Kien, N.V. Pham Huynh Thanh Van, Huynh Ngoc Duc, Tran Van Hieu, Pham Xuan Phu, Nguyen Van Thai. 2012. *The importance of the conservation and development of floating rice in the Mekong Delta.* Unpublished report. An Giang University, Vietnam.

Ma Lizbeth Barona. 2012. *A chance in the wild.* Science Short. Special Reports on website of IRRI. Available at: http://irri.org/index.php?option=com_k2&view=item&id=12066:a-chance-in-the-wild&lang=en.

Pamela McElwee and Micheal Horowitz. 1999. *Prepared for the Mekong River Basin Research and Capacity Building Initiative.* The Institute for Development Anthropology. Oxfam America SEA, 15. 197-99 pp.

McNamee, P. 1998. *Measures for sustainable development in the inland wetland area in the Mekong Delta.* ESCAP virtual conference. Available online at: http://www.unescap.org/drpad/vc/conference/bg_vn_1_msd.htm.

Michael Graham Richard. 2009. *Inexpensive Arsenic Filtration System Based on Cattails Could Help Clean Up the Drinking Water of 57 Million People.* Tree Hugger website. Available online at: http://www.treehugger.com/lawn-garden/inexpensive-arsenic-filtration-system-based-on-cattails-could-help-clean-up-the-drinking-water-of-57-million-people.html.

NAFRI, NUoL, SNV. 2007. *Non-timber forest products in the Lao PDR. A manual of 100 commercial and traditional products*. The National Agriculture and Forestry Research Institute, Vientiane, Lao PDR. Quoting Mollot et al. (2004).

Chanhsamone Phongoudome, Bounphom Mounda, Khamphay Manivong, Silavanh Sawathvong, Saykham Bouthavong and Boualy Phamuang. 2009. *Report On The National Program Assessment on Forest of Lao PDR.*

Phung Huu Chinh, Nguyen Hung Minh, Pham Hong Thai and Nguyen Quang Tan. 1995. *Rafter Beekeeping in Melaleuca Forests in Vietnam.* Bees for Development Journal 36. 8–9 pp.

School of Biological Sciences, University of Aukland website. Available online at: http://web.auckland.ac.nz/uoa/science/about/departments/sbs/newzealandplants/maoriuses/food/herbs/raupo-typha.cfm.

Stibig, H.J., Stolle F., Dennis R. & Feldkötter C. 2007. *Forest Cover Change in Southeast Asia: The Regional Pattern*. European Commission Joint Research Centre.

Zareen Bharucha and Jules Pretty. *The roles and values of wild foods in agricultural systems.* Phil. Trans. R. Soc. B 2010 365, 2913-2926. doi: 10.1098/rstb.2010.0123. Downloaded from http://rstb.royalsocietypublishing.org on June 4, 2012.

World Crop website. Water Spinach Ipomoea aquatica. Available at: http://www.worldcrops.org/crops/Water-Spinach.cfm.

Vietnam News. Delta farmer creates 19 new robust high-yield rice strains. http://vietnamnews.vnagency.com.vn/Agriculture/224113/delta-farmer-creates-19-new-robust-high-yield-rice-strains.html.

Engel, Michael S. 1999. *The taxonomy of recent and fossil honey bees (Hymenoptera: Apidae: Apis)*. Journal of Hymenoptera Research 8: 165–196 pp.

Robinson, WS. 2012. *Migrating Giant Honey Bees (Apis dorsata) Congregate Annually at Stopover Site in Thailand.* PLoS ONE 7(9): e44976. doi:10.1371/journal.pone.0044976.

F.C Dyer and Th.D Seeley. 1994. *Colony migration in the tropical honey beeApis dorsata F. (Hymenoptera: Apidae).* Insectes Sociaux. 1994, Volume 41, Issue 2. 129–140 pp.

Gallai, n., salles, J.m., settele, J. & vaissiere, B.e. 2009. *Economic valuation of the vulnerability of world agriculture confronted with pollinator decline.* Ecol Econom, 68: 810–821 pp.

I.F. Ibrahim, S.K. Balasundram, N.A.P. Abdullah, M.S. Alias and M. Mardan, 2012. *Morphological Characterization of Pollen Collected by Apis dorsata from a Tropical Rainforest.* International Journal of Botany, 8: 96–106 pp.

Y. Le Conte & M. Navajas. 2008. *Climate change: impact on honey bee populations and diseases.* Rev. sci. tech. Off. int. Epiz., 2008, 27 (2), 499–510 pp.

Phung Huu Chinh, Nguyen Hung Minh, Pham Hong Thai and Nguyen Quang Tan. 1995. *Rafter Beekeeping in Melaleuca Forests in Vietnam*. Bees for Development Journal 36. 8–9 pp. (Phung Huu Chinh et al, 1995).

Rattanawannee, A., Chanchao, C., Lim, J., Wongsiri, S. and Oldroyd, B. P. 2012. *Genetic structure of a giant honey bee (Apis dorsata) population in northern Thailand: implications for conservation.* Insect Conservation and Diversity. doi: 10.1111/j.1752-4598.2012.00193.x.

*List of database websites for species*

- www.fao.org/forestry/nwfp - database of NTFPs
- http://www.fao.org/forestry/64431/en/ - this is the digest of literature on NWFPs
- http://www.fao.org/forestry/edibleinsects/65425/en/ - for edible insects
- http://www.ent.wur.nl/UK/Edible+insects/Worldwide+species+list/ - lists edible insect species throughout the world
- www.protectedplanet.net – descriptions of protected areas around the world
- www.wdpa.org – World Database on Protected Areas
- http://ebsa.cbd.int/ - key biodiversity areas
- www.birdlife.org/action/science/sites - Important bird areas
- www.plantlife.org.uk/wild_plants/important_plant_areas - important plant areas
- www.hcvnetwork.org – High Conservation resource network
- www.worldagroforestry.org – database of agroforestry crops
- www.tropicalforages.info – database of forage crops
- http://ecocrop.fao.org/ecocrop/srv/en/home – database on ecological requirements of many crop species
- www.iucnredlist.org – Red List of threatened species also go *to* http://maps.iucnredlist.org
- www.ibatforbusiness.org – tool for business to identify areas and species close to areas of operation
- www.iucnredlistofecosystems.org – under development
- www.issg.org/database/welcome – global invasive species
- www.theplantlist.org – working list of all plant species
- http://www.catalogueoflife.org
- www.eol.org – Encyclopedia of Life
- www.tropicos.org – Tropicos® was originally created for internal research but has since been made available to the world's scientific community. All of the nomenclatural, bibliographic, and specimen data accumulated in MBG's electronic databases during the past 25 years are publicly available here. This system has over 1.2 million scientific names and 4.0 million specimen records.
- www.efloras.org – database of flora from different countries
- www.Mushroomexpert.com

- http://www.knowledgebank.irri.org/ – rice knowledge bank by IRRI including wild rice taxonomy
- http://www.knowledgebank.irri.org/extension/index.php/wild-rice-taxonomy
- http://zipcodezoo.com/
- http://en.hortipedia.com/wiki
- http://en.uuuwell.com
- http://www.cwrdiversity.org/home/ – FAO database of crop wild relatives

## Natural systems – protected areas

Adger, W.N. 2003. *Social capital, collective action and adaptation to climate change.* Economic Geography 79, 387–404 pp.

Birdlife International. Nong Bong Kai Ramsa fact sheet. http://www.birdlife.org/datazone/sitefactsheet.php?id=15086.

CIFOR. 2012. *Adapting forests and people to climate change.* Conserving ecosystem services that reduce risk to the world's poorest - A framework proposal.

Crooks, K.R. and Sanjayan, M. 2006. *Connectivity Conservation.* Cambridge University Press, Cambridge.

Department of Environment, Climate Change and Water NSW DECCW. 2010. Priorities for Biodiversity Adaptation to Climate Change, Statement of Intent in response to the listing of Anthropogenic Climate Change as a Key Threatening Process under the NSW Threatened Species Conservation Act 1995.

Dubois, N., A. Caldas, J. Boshoven, and A. Delach. 2011. *Integrating Climate Change Vulnerability Assessments into Adaptation Planning: A Case Study Using the NatureServe Climate Change Vulnerability Index to Inform Conservation Planning for Species in Florida [Final Report].* Defenders of Wildlife, Washington D.C.

F. Boltz, H. Balasubramanian, and M. Morales – Protected Area Management Plan recommended Elements.

Gitay, H., Finlayson, C.M. & Davidson, N.C. 2011. *A Framework for assessing the vulnerability of wetlands to climate change*. Ramsar Technical Report No. 5/CBD Technical Series No. 57. Ramsar Convention Secretariat, Gland, Switzerland & Secretariat of the Convention on Biological Diversity, Montreal, Canada. ISBN 92-9225-361-1 (print); 92-9225-362-X (web).

ICEM. 2003a. *Cambodia National Report on Protected Areas and Development.* Review of Protected Areas and Development in the Lower Mekong River Region, Indooroopilly, Queensland, Australia.

ICEM. 2003b. Lao People's Democratic Republic, National Report on Protected Areas and Development, Indooroopilly, Queensland, Australia.

ICEM. 2003c. Thailand, National Report on Protected Areas and Development, Indooroopilly, Queensland, Australia.

ICEM. 2003d. Vietnam, National Report on Protected Areas and Development, Indooroopilly, Queensland, Australia.

ICEM. 2003e. *Regional Report on Protected Areas and Development.* Review of Protected Areas and Development in the Lower Mekong River Region, Indooroopilly, Queensland, Australia.

IPCC. 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* IPCC, Geneva, Switzerland.

Kathiresan K. 2012. *Importance of Mangrove Systems*. International Journal of Marine Science Vol. 2, No. 10. http://bio.sophiapublisher.com/html-521-32-ijms.

MA – Millennium Ecosystem Assessment . 2005. 'Millennium Ecosystem Assessment, General Synthesis Report', Island Press, Washington D.C.

MONRE. 2009. MDCC – MEKONG DELTA CLIMATE CHANGE FORUM, Volume I.

MRC, ICEM. 2012. *Basin-wide Climate Change Impact and Vulnerability Assessment for the Wetlands of the Lower Mekong Basin for Adaptation Planning*. Final regional workshop. Phnom Penh, 2-3 Feb 2012.

Olmos, S. 2001. Vulnerability and Adaptation to Climate Change: Concepts, Issues, Assessment Methods, the Climate Change Knowledge Network.

Palmer, C., Falco. S. D. 2012. *Biodiversity, poverty and development, Oxford Review of Economic Policy*. Volume 28, Number 1.

Private Land partnerships working together for wildlife – Wetland restoration technique, Part IV: Wetland Management.

Salathé, T. 2003. *Climatic change and foreseeable impacts on deltas: a new challenge for the conservation of protected areas, climate change and deltas.* Seminar in Italy.

Stolton. S., Dudley. N, 2010. *Managing for climate change – developing strategies for protected area managers.* Results of a Seminar organised by BfN and the United National Development Programme at the International Academy for Nature Conservation on the Island of Vilm, Germany.

TEEB. 2010. *The Economics of Ecosystems and Biodiversity.* Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.

WWF. 2013. *Ecosystems in the Greater Mekong: Past trends, current status, possible futures*. WWF Greater Mekong.

## Socio-economics

Asian Development Bank (ADB). 2010. 'GMS Migration Policy Briefing Extracts from an ABD Project entitled "Forecasting Migration Flows: The Relationships among Economic Development, Demographic Change and Migration in the Greater Mekong Sub-region".

Asian Development Bank (ADB). 2011. 'Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects', available at: http://www.adb.org/documents/guidelines-climate-proofing-investment-transport-sector-road-infrastructure-projects.

AusAID. 2013. 'Website of the Conservation and Development of the KiengGiang Biosphere Project', available at: http://kiengiangbiosphereserve.com.vn/project/index.php.

Bain, R.E.S., Gundry, S.W., Wright, J.A., Yang, H., Pedley, S. and J.K. Bartram. 2012. *Accounting for water quality in monitoring access to safe drinking water as part of the Millenium Development Goals: Lessons from five countries.* Bulletin of the World Health Organisation, 90: 228-235A.

Bapna, M., McGray, H., Mock, G. and L. Withey. 2009. *Enabling Adaptation: Priorities for Supporting the Rural Poor in a Changing Climate.* World Resources Institute Issue Brief.

Bennett, M.T. 2008. *China's sloping land conversion program: Institutional Innovation or business as usual?* Ecological Economics, 64(4): 699–711 pp.

Brody, A., Demetriades, J. and E. Esplen. 2008. *Gender and climate change: mapping the linkages. A scoping study on knowledge and gaps.* BRDIGE, available at: http://www.bridge.ids.ac.uk/reports/Climate_Change_DFID.pdf.

CGIAR/FAO. 2011. *Gender and Climate Change Research in Agriculture and Food Security for Rural Development: Training Guide.* Available at: http://www.fao.org/docrep/015/md280e/md280e00.htm.

Chiang Rai Financial Office. 2010. *Gross Provincial Products of Chiang Rai.* Available at: http://klang.cgd.go.th/cri. (in Thai).

Chiang RaiGoverner's Office. 2012. *Chiang Rai Development Plan for 2010–2013.* (in Thai).

Chiang Rai Official Website. 2012. Available at: http://www.ChiangRai.go.th/cpoc/2011.

Committee on Climate Change and U.S. Transportation. 2008. *Potential Impacts of Climate Change on U.S. Transportation: Special Report 290.* National Research Council of the National Academies. Available at: http://www.nap.edu/catalog/12179.html.

DECIDE INFO. 2012. Lao DECIDE- info project, mapping and statistics database of the Lao national Population and Housing Census 2005. Available at: http://www.decide.la.

Douven, W.J.A.M., M. Goichot and H.J. Verheij. 2009. *Best Practice Guidelines for the Integrated Planning and Design of Economically Sound and Environmentally Friendly Roads in the Mekong Floodplains of Cambodia and Viet Nam.* Synthesis report of the 'Roads and Floods' project (part of MRC-FMMP Component 2). MRC Technical Paper No. 35, Mekong River Commission, Office of the Secretariat in Phnom Penh.

Food and Agriculture Organisation (FAO). 2011. Special Report: FAO/WFP Crop and Food Security Assessment Mission to Lao People's Democratic Republic.

Food and Agriculture Organisation FAO. 2012. Invisible Guardians: Women manage livestock diversity. Available online at: http://www.fao.org/docrep/016/i3018e/i3018e00.htm.

General Statistics Office of Vietnam (GSO). 2011. Result of the Viet Nam Household Living Standards Survey 2010. Available at: http://www.gso.gov.vn/default_en.aspx?tabid=515&idmid=5&ItemID=12426.

General Statistics Office of Vietnam (GSO). 2012. Vietnam Statistics Online. Available at: http://www.gso.gov.vn.

Goh, A.H.X. 2012. A literature review of the gender-differentiated impacts of climate change on women's and men's assets and well-being in developing countries. CAPRi Working Paper No. 106. Washington, D.C.: International Food Policy Research Institute. Available at: http://dx.doi.org/10.2499/CAPRiWP106.

Governance Reform and Livelihood Strengthening Programme (GPARLSP). 2006. 'Natural Resource Management in Khammouane Province'.

Hook, J., Novak, S. and R. Johnston. 2003. *Social Atlas of the Lower Mekong Basin', Mekong River Commission.* Available at: http://www.mrcmekong.org/assets/Publications/basin-reports/social-Atlas-of-the-LMB.pdf.

ICEM. 2013a. *Mekong ARCC Climate Change Vulnerability and Adaptation Assessment - Climate Change Modelling Report.*

ICEM. 2013b. Bioengineering Project in Northern Provinces of Vietnam - http://icem.com.au/category/bioengineering-project/.

ICEM. 2011. *Climate Change Adaptation and Mitigation (CAM) Methodology Brief.* ICEM – International Centre for Environmental Management. Hanoi, Vietnam.

International Organisation for Migration (IOM). 2009. *Mapping Vulnerability to Natural Hazards in Mondulkiri.*

International Panel on Climate Change (IPCC). 2012. *Managing the risks of extreme events and disasters to advance climate change adaptation*.

Johnston, R., Hoanh, C. T., Lacombe, G., Noble, A., Smakhtin, V. and D. Suhardiman. 2009. *Scoping Study on Natural Resources and Climate Change in Southeast Asia with a Focus on Agriculture.* Report prepared for the Swedish International Development Cooperation Agency by International Water Management Institute. Available at: http://publications.iwmi.org/pdf/H042414.pdf.

Konig, H.J., Zhen, L., Helming, K., Uthes, S., Yang, L., Cao, X. and H. Wiggering. 2012. *Assessing the Impact of the Sloping Land Conversion Programme on Rural Sustainability in Guyuan, Western China*. Land Degradation & Development. Pre-publication.

Lao Institute for Renewable Energy (LIRE). 2013. *Renewable Energy, Country Situation Analysis: Lao PDR.* Presentation to ICEM on 21 February 2013, available upon request.

Lao Statistic Bureau. 2010. *Fourth Expenditure and Consumption Survey.* Available at: http://www.nsc.gov.la/index.php?option=com_content&view=article&id=50&Itemid=73&lang=

Lebel, P., Chaibu, P. and L. Lebel. 2009. *Women Farm Fish: Gender and Commercial Fish Cage Culture on the Upper Ping River, Norhern Thailand*. Gender, Technology and Development. 13(2): 199–224 pp.

Mackay, P. 2009. *Participatory Socio-Economic Survey: A Socio-Economic Baseline Survey of Coastal Communities in KienGiang Biosphere Reserve*. Available at: http://kiengiangbiospherereserve.com.vn/project/index.php?download/4/24.

Mackay, P. and M. Russell. 2011a. *Climate Change Impact and Adaptation Study in the Mekong Delta – KienGiang Atlas', Asian Development Bank*. Available at: http://www.adb.org/projects/documents/climate-change-impact-and-adaptation-study-mekong-delta-part-a-kien-giang-atlas-tacr.

Mackay, P. and M. Russell. 2011b. *Climate Change Impact and Adaptation Study in The Mekong Delta – Part A, Final Report.* Available at: http://www.adb.org/sites/default/files/projdocs/2012/43295-012-vie-tacr-03_0.pdf.

Mainuddin, M., Kirby, M. and C. T. Hoanh. 2011. *Adaptation to climate change for food security in the lower Mekong Basin.* Food Security, 3(4): 433-50.

McMichael, A. J., Woodruff, R. E. and S. Hales. 2006. *Climate change and human health: present and future risks.* Lancet, 367: 859-69.

Mekong River Commission (MRC). 2010. *State of the Basin Report 2010.* Available at: http://www.mrcmekong.org/assets/Publications/basin-reports/MRC-SOB-Summary-reportEnglish.pdf.

Ministry of Public Health, Bureau of Policy and Strategy. 2010. Public Health Statistics (Thailand), (in Thai and English).

Nam Theun 2 Power Company Health Program Management Unit, Environment and Social Division. 2008. Health Checks and Survey for Resettled Populations, December 2005–February 2008. Available at: http://www.namtheun2.com/images/stories/General/Health Checks Report All Villages - Final Report.pdf.

National Committee for Sub-National Democratic Development (NCDD). 2009. 'MondulKiri Data Book 2009'.

National Committee for Sub-National Democratic Development (NCDD). 2010. 'Provincial/Municipal Profile 2010 – General Information of the province'.

National Statistical Office (Thailand).Ministry of Information and Communication Technology. 2012. Key Statistics of Thailand, (in Thai and English).

NT2PC (Nam Theun 2 Power Company Health Program Management Unit, Environment and Social Division). 2008). 'Health Checks and Survey for Resettled Populations, December 2005–February 2008. Available at: http://www.namtheun2.com/images/stories/General/Health Checks Report All Villages - Final Report.pdf.

Nellemann, C., Verma, R., and L. Hislop (eds). 2011. 'Women at the frontline of climate change: Gender risks and hopes. A Rapid Response Assessment', United Nations Environment Programme/GRIDA. Available online at: http://www.grida.no/publications/rr/women-and-climate-change.

Nghia, T.N. 2000. *'Non-Timber Forest Product-Gender Analysis and Gender Action Plan'.* Non-Timber Forest Products Research Center. Available online at: http://www.mekonginfo.org/assets/midocs/0003299-society-ntfp-gender-analysis-and-gender-action-plan.pdf.

Nguyen, T.N.M. and J. Sawdon. 2010. 'Climate Change and Coastal Ecosystems Programme: Gender Analysis'. Available online at: http://www.ausaid.gov.au/Publications/Pages/4010_672_1799_4027_3801.aspx.

Office of Agricultural Economics. Ministry of Agriculture and Cooperatives. 2010. *Agricultural Statistics of Thailand 2009.* (in Thai and English).

Office of the National Economic and Social Development Board. 2012. National Economic and Social Development Database (Thailand) website. Available at: http://region1.nesdb.go.th/economy/web/form.jsp.

Onda, K., LoBuglio, J. and J. Bartram. 2012. 'Global Access to Safe Water: Acocunting for Water Quality and the Resulting Impact on MDG Progress', *International Journal of Environmental Research and Public Health*, 9(3): 880–894 pp.

Orr, S, Pittock, J, Chapagain, A and D. Dumaresq. 2012. 'Dams on the Mekong River: Lost fish protein and the implications for land and water resources', *Global Environmental Change: Part A - Human and Policy Dimensions,* 22(4): 925-32.

Oxfam/UN Vietnam. 2009. 'Responding to Climate Change in Vietnam: Opportunities for improving gender equality'. Available online at: http://policy-practice.oxfam.org.uk/publications/responding-to-climate-change-in-vietnam-opportunities-for-improving-gender-equa-112555.

8 BIBLIOGRAPHY AND REFERENCES

Portier, C. J. and K. T. Tart. 2010. *A Human Health Perspective on Climate Change: A Report Outlining the Research Needs on the Human Health Health Effects of Climate Change.* The Interagency Working Group on Climate Change and Health, Environmental Health Perspectives and the National Institute of Environmental health Sciences. Available at: http://www.niehs.nih.gov/health/assets/docs_a_e/climatereport2010.pdf.

Saigon Times. 2012. 'First floating toilet in Vietnam in Can Tho', May 29, 2012. Available at: http://english.thesaigontimes.vn/ArticleVideoDetails.aspx?ID=23698.

Sherwood, S. and M. Huber. 2010. 'An adaptability limit to climate change due to heat stress', *Proceedings of the National Academy of Sciences*, 107(21): 9552-55.

Sterrett, C. 2011. *Review of Climate Change Adaptation Practices in South Asia.* Oxfam Research Reports.

Tisdell, C. 2010. *The Competitiveness of Small Household Pig Producers in Vietnam: Significant Research and Policy Findings and Policy Findings from an ACIAR-sponsored Study and their Limitations.* Working Paper No. 63, Economic Theory, Applications and Issues Series, University of Queensland, http://ageconsearch.umn.edu/bitstream/97471/2/WP 63.pdf.

UNDP. 2010. *Gender, Climate Change and Community-Based Adaptation.* Available online at: http://www.undp.org/content/undp/en/home/librarypage/environment-energy/climate_change/gender/gender-climate-change-and-community-based-adaptation-guidebook-/.

UNICEF. 2011. *Children and Women in Thailand: UNICEF Situation Analysis.* (in Thai).

United Nations. 2010. 'Internal Migration: Opportunities and challenges for socio-development in Viet Nam'. Available at: http://www.un.org.vn/en/publications/doc_details/173-internal-migration-opportunities-and-challenges-for-socio-economic-development-in-viet-nam.html.

United Nations. 2011. World Urbanisation Prospects, 2011 Revision. Available at: http://esa.un.org/unpd/wup/index.htm.

United Nations. 2010. World Population Prospects, 2010 Revision. Available at: http://esa.un.org/unpd/wpp/index.htm.

USAID. 2008. Vietnam Central Highlands Needs Assessment. Available at: http://www.oecd.org/countries/vietnam/42305730.pdf.

Vietnam-Netherlands Cooperation. 2011. 'Towards a Mekong Delta Plan - Workplan'. Available at: http://www.partnersvoorwater.nl/wp-content/uploads/2011/09/Annex1_WorkplanMDPVolumeI_finalversionDecember12010_.pdf.

World Bank. 2011a. 'Vulnerability, Risk Reduction, and Adaptation to Climate Change: Lao P.D.R'. Climate Change Risk and Adaptation Country Profile.

World Bank. 2011b. 'Vulnerability, Risk Reduction, and Adaptation to Climate Change: Cambodia'. Climate Change Risk and Adaptation Country Profile.

World Bank. 2011c. 'Vulnerability, Risk Reduction, and Adaptation to Climate Change: Vietnam'. Climate Change Risk and Adaptation Country Profile.

World Bank. 2013. World Development Indicators. Available at: http://data.worldbank.org/data-catalog/world-development-indicators.

World Conservation Society WCS. 2008. *A survey of communities in and around the Seima Biodiversity Conservation Area in 2008.*

World Food Programme. 2007. 'Lao PDR: Comprehensive Food Security & Vulnerability Analysis'. Available at: http://www.wfp.org/content/lao-pdr-comprehensive-food-security-and-vulnerability-analysis-2007.

World Food Programme. 2008. 'Cambodia:Comprehensive Food Security & Vulnerability Analysis'. Available at: http://home.wfp.org/stellent/groups/public/documents/ena/wfp227417.pdf.

World Health Organisation. 2011. 'Gender, Climate Change and Health'. Available at: http://www.who.int/globalchange/publications/reports/gender_climate_change/en/.

World Health Organization/World Meteorological Organization (WHO/WMO). 2012. Atlas of Health and Climate. Available at: http://www.who.int/globalchange/publications/atlas/en/index.html.

World Wildlife Fund for Nature. 2007. *'Socio-economic profile of communities around the Mondulkiri Protected Forest'.*

World Wildlife Fund for Nature (WWF)/Wilderness Conservation Society (WCS). 2009. *'Livelihoods sustainability Analysis in Mondulkiri Province'.*

WRINET. 2006. 'Vietnam: Situation of Indigenous Minority Groups in the Central Highlands', report commissioned by the UNHCR, available at: http://www.unhcr.org/refworld/pdfid/44c0f55a4.pdf.

Western Highlands Agro-Forestry Scientific & Technical Institute. 2012. *An overview on Sesan catchment.* Available upon request.

## Climate threat modeling

Eastham, J., F. Mpelasoka, M. Mainuddin, C.Ticehurst, P. Dyce, G. Hodgson, R. Ali and M. Kirby, 2008. *Mekong River Basin Water Resources Assessment: Impacts of Climate Change.* CSIRO: Water for a Healthy Country National Research Flagship.

IPCC. 2000. *IPCC Special Report: Emissions scenarios summary for policy makers,* Special report for Working Group III of the Intergovernmental Panel for Climate Change. ISBN: 92-9169-113-5 IPCC.

IPCC. 2007. *Fourth Assessment Report of the IPCC: Synthesis Report.* Intergovernmental Panel for Climate Change.

MacSweeney, C., Jones, R.G, Booth, B.B.B. 2011. *Selecting ensemble members to provide regional climate change information.* Met Office Hadley Cenre, Firtzroy Road Exeter.

Cai,X., Wang,D., Zhu,T. & Ringler,C. 2009. Assessing the regional variability of GCM simulations. *Geophysical Research Letters*, **36:** L02706, doi:10.1029/2008GL036443. Chandler R., Rougier, J., Collins, M. 2010. Climate Change: making certain what the uncertainties are. Significance march 2010, United Kingdom.

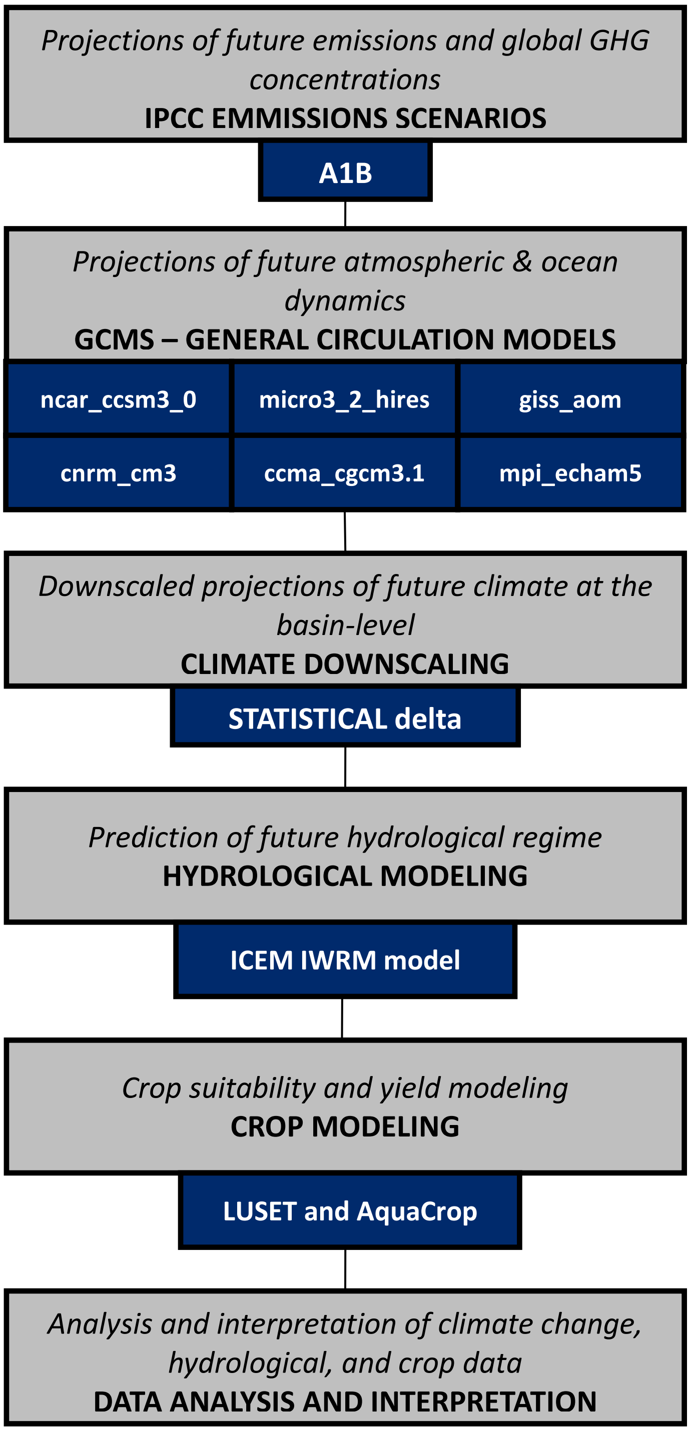
MRCS. 2010. *Studies on impacts of basin development on wetlands and biodiversity.* For the Basin Development Plan.

Sys, Ir. C., E. Van Ranst, J. Debaveye and F. Beernaert. 1993. *Land Evaluation Part III - Crop requirement.* Belgium General Administration for Development Cooperation. Agricultural Publications No. 7.

# ANNEX 1: CLIMATE CHANGE MODELING

The study followed a five-step process to identify climate threats starting from IPCC emissions scenarios and ending with specific threats at the province level (Figure A-1).

**Figure A-1: Climate change threat assessment workflow**



The process involves a number of tools and methodologies. This annex provides a detailed description of the approach, assumptions, and validation efforts of the three critical phases: climate change scenario downscaling, hydrological modeling, and delta flood modeling.

## 8.1 CLIMATE CHANGE SCENARIO DOWNSCALING

In order to assess the potential impact of climate change on hydrological processes, it is essential to downscale GCM[61] data as the spatial resolution of GCMs (i.e., the size of the grid cells) is too coarse for hydrological modeling. The downscaling process encompasses several activities: (i) data collection, (ii) statistical downscaling, and (iii) spatial interpolation.

### 8.1.1 DATA COLLECTION

#### 8.1.1.1 GCM selection

GCMs were selected based on their performance in replicating historical precipitation in the SE Asia region. Two studies were used to aid in the selection of GCMs: a global study by Cai et al. (2009) comparing the output of 17 GCMs to IPCC Climate Research Unit data[62]; and a study by Eastham et al. (2008) which assessed the 24 GCMs of the 4th IPCC assessment report (AR4) and identified 11 that performed well in the Mekong region for temperature and precipitation.

There are three models that performed well in both studies (ccma_cgcm3.1 (Canada), cnrm_cm3 (France), and ncar_ccsm3 (USA)) (Table A-1). Two other models were chosen because they performed particularly well in the Eastham et al (2008) study, which was specifically focussed on SE Asia and the Mekong. The final GCM - mpi_echam5 - was chosen because it has already been used in the Mekong area and been shown to perform well (Vastila et al. 2010).

**Table A-1: Comparison of GCM performance in the Mekong Region:** *GCMs that show good correlation to historical precipitation in the Mekong Basin. Blue shading indicates GCM shown to perform well in the region by both studies. Grey shading indicates GCM that performed particularly well in Eastham et al. (2008) or another study.*

| Model | Institute/Country | Cai et al. (2009) | Eastham et al. (2008) |
|---|---|---|---|
| ncar_ccsm3_0 | NCAR / USA | Good | Good |
| miub_echo_g | MIUB / Germany | not assessed | Good |
| micro3_2_medres | CCSR / Japan | | Good |
| micro3_2_hires | CCSR / Japan | | Good |
| inv_echam4 | MPI / Germany | not assessed | Good |
| giss_aom | GISS / USA | | Good |
| csiro_mk3_0 | CSIRO / Australia | | Good |
| cnrm_cm3 | CNRM / France | Good | Good |
| cccma_cgcm3_1_t63 | CCCMA / Canada | not assessed | Good |
| cccma_cgcm3_1 | CCCMA / Canada | Good | Good |
| bccr_bcm2_0 | BCCR / Norway | not assessed | Good |
| gfdl_cm2.1 | GFDL / USA | Good | not assessed |
| mpi_echam5 | MPI / Germany | Good | |

[61] Global Circulation Model or Global Climate Model
[62] The IPCC Climate Research Unit (CRU) Global Dataset is an IPCC-endorsed historical dataset for 11 meteorological parameters covering all global land areas except Antarctica. The dataset can be accessed from http://www.ipcc-data.org/obs/cru_climatologies.html

In summary the study chose the following six GCMs that exhibited the best validity for the LMB:

(i) ccma_cgcm3.1 (CCCMA Canada)
(ii) cnrm_cm3 (CNRM France)
(iii) ncar_ccsm3_0 (NCAR USA)
(iv) miroc3_2_hires (CCSR Japan)
(v) giss_aom (GISS USA)
(vi) mpi_echam5 (MPI Germany)

For the selected GCMs the A1b scenario results (550 ppm stabilization) were obtained from the WCRP CMIP3 multi-model database[63] (Table A-2). The model results found in the database were developed for the IPCC AR4. The models had various spatial resolutions, varying between just over 1° to about 4° cells (Figure A-2).

Output covering the 20th and 21st century was used for the downscaling. Some of the GCMs had runs available going beyond 2100 but in these runs no extra increase in atmospheric carbon was simulated beyond the 21st century so downscaling was not undertaken past 2100. For some of the models more than one run was available in the data portal, in which case the first run was taken.

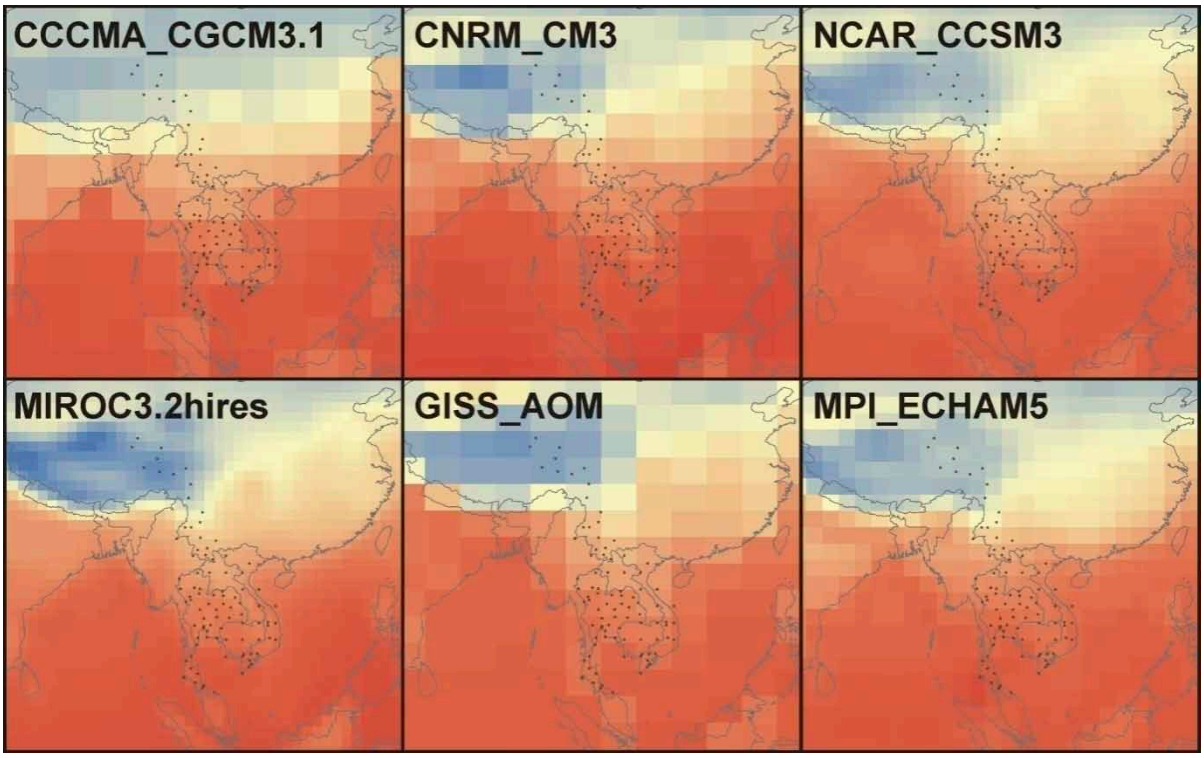
Monthly output for average surface temperature (tas) and precipitation (pr) was retrieved. It was decided not to use the daily output of the GCMs as the daily output was not available for continuous series, but only for time slices.

**Table A-2: GCMs data retrieved from the WCRP CMIP3 multi-model database**

| GCM | Scenario | Time Frame | Spatial Resolution | GCM |
|---|---|---|---|---|
| cccma_cgcm3. 1 | A1b | 1850-2300 | 3.75° x 3.75° | cccma_cgcm3. 1 |
| cnrm_cm3 | A1b | 1860-2299 | ~2.8° x 2.8° | cnrm_cm3 |
| ncar_ccsm3 | A1b | 1870-2099 | ~1.4° x 1.4° | ncar_ccsm3 |
| miroc3.2hires | A1b | 1900-2100 | ~1.1° x 1.1° | miroc3.2hires |
| giss_aom | A1b | 1850-2100 | 3° x 4° | giss_aom |
| mpi_echam5 | A1b | 1860-2200 | ~1.9° x 1.9° | mpi_echam5 |

63 https://esg.llnl.gov:8443/home/publicHomePage.do

**Figure A-2: Overview of the different spatial resolutions of the GCMs:** *The background colour denotes temperatures with blue as cold and red as warm temperatures. The dots correspond with the Mekong Basin temperature stations.*

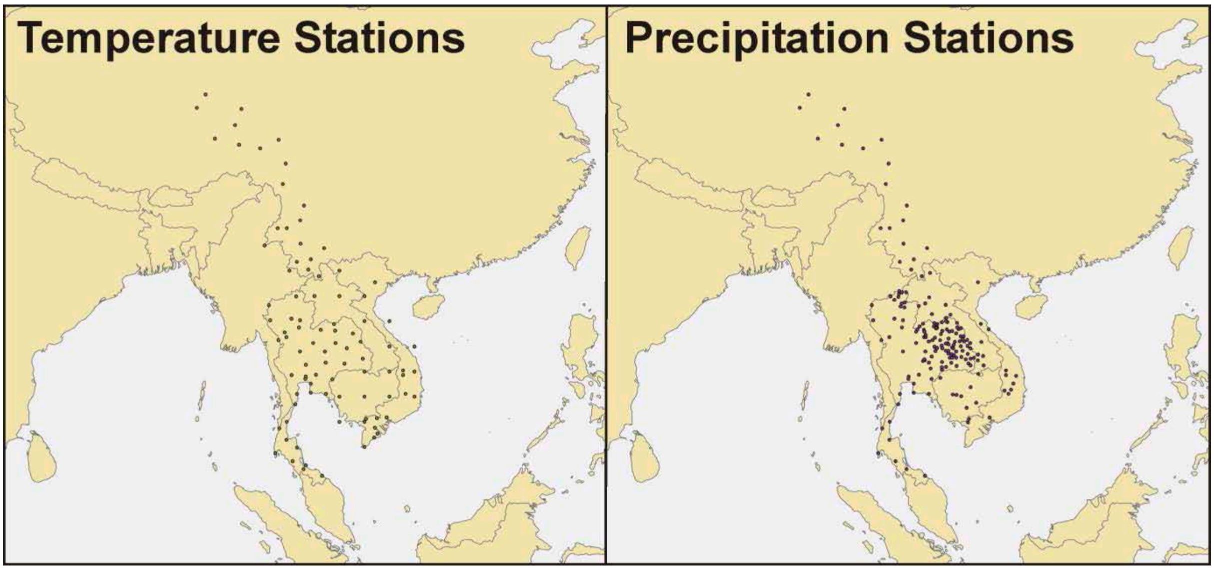



### 8.1.1.2 Observation data

Observed daily data was obtained for the period 1981–2005 for 151 precipitation stations, and 61 temperature stations in the LMB (Figure A-3). Due to data availability and quality issues the observed data was only available for a 25 year period (Lauri et al. 2012). Precipitation data was extracted from the MRC hydro-meteorological database (MRC 2011). Average temperature, minimum temperature, and maximum temperature measurements were obtained from the MRC database and supplemented with NCEP-DOE Reanalysis 2 data[64] in locations in Lao PDR and Cambodia where there was poor coverage. There were a few missing data values in the series, usually individual days and sometimes two days in a row. These gaps where filled with the temperature of the day before in all three temperature series and for precipitation they were filled with 0 mm precipitation.

[64] NCEP-DOE Reanalysis 2 is a global historical temperature dataset prepared by the National Oceanic and Atmospheric Administration, US Department of Commerce. The dataset is available at http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis2.html

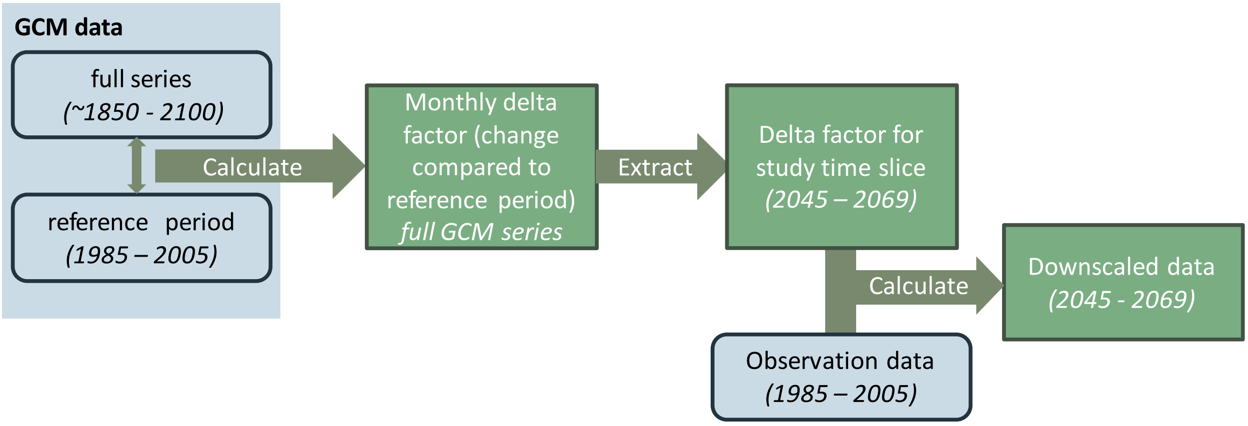
Figure A-3: Location of the stations for which observed data was obtained




### 8.1.2 DOWNSCALING

The study downscaled the GCM data using the delta method (see, e.g., Lauri et al. 2012; Diaz-Nieto and Wilby 2005; Choi et al. 2009). In order to create future time series on a daily basis, the delta method takes changes between a baseline and future period in the GCM data and superimposes them onto the daily observed time series (Figure A-4).

Figure A-4: The downscaling process




The change factor (known as delta factor) was determined from the GCM data. Changes in the monthly GCM data between a climatic reference period (1981–2005) and future period were calculated for each month using a moving window of 25 years—i.e., 12 years before, the year itself, and 12 years after. The change was calculated over 25 year periods in order to extract the long-term trend from the GCM output and not the annual variation. The delta factors were calculated for each month present in the GCM time series, which in the longest case was from 1862–2288 (Lauri et al. 2012).

In order to account for differences between observed and modeled variability, the delta factors for temperature were calculated as a fraction of the standard deviation (see equation 1). For precipitation the relative increase in average precipitation was calculated as a fraction of the series mean[65] (see equation 2).

$$\Delta_{TMP} = \frac{\bar{T}_{series,i} - \bar{T}_{ref,i}}{\sigma_{ref,i}} \qquad (1)$$

$$\Delta_{PRE} = \frac{\bar{P}_{series,i}}{\bar{P}_{ref,i}} \qquad (2)$$

*where $\bar{T}_{series,i}$ and $\bar{P}_{series,i}$ are the (25 year) average for month i of a particular time month in the GCM time series. $\bar{T}_{ref,i}$ and $\bar{P}_{ref,i}$ are the (25 year) averages for temperature and precipitation for the reference period 1981–2005 for month i and $\sigma_{ref,i}$ is the standard deviation of the monthly average temperature during the reference period for month i.*

The calculated delta factors were used to perturb a daily time series created by replicating the observed 25 years. The observed series was replicated so that the total length corresponded exactly with the length of each of the GCM time series. The delta factor found for a specific month (e.g., March 2035) was subsequently used to adjust all daily data in that month (e.g., the 1st of March through the 31st of March 2035). Temperatures were increased by the amount of standard deviations denoted by the delta factor[66] and precipitation was multiplied with the delta factor.

The downscaling procedure resulted in daily time series for 1900–2100 for each of the 151 precipitation stations, and 61 temperature stations. Some GCMs also provided data from before 1900, or later than 2100 but given the time slice focus of the study these results were not used. The results for the project time slice (2045–2069) were extracted from the longer time series.

### 8.1.3 DATA INTERPOLATION

To enable hydrological modeling the downscaled temperature and precipitation daily time series for each meteorological station was interpolated to a 5 km by 5 km grid. Temperature and precipitation were interpolated for each model grid cell from the three nearest observation locations using inverse distance weighting and elevation corrections. Elevation correction factors were used to modify the downscaled data using the difference of elevation between the model grid cell elevation and the elevation of the measurement stations. For precipitation, a multiplicative correction was used with multiplier 1+0.0002 h, where h is the elevation difference in meters. For temperature, an additive correction with addition of −0.006 h was used. The interpolation procedure is described in detail by Lauri et al. (2012).

[65] Precipitation does not follow a Gaussian distribution. So for precipitation the standard deviation is not a proper indicator for the variation and the mean is used to account for differences between observed and modeled variability.

[66] It was assumed that no change in the diurnal cycle of temperature occurs. This is a necessary assumption as the monthly GCM data does not contain any information on the maximum and minimum temperatures. Therefore the average temperature, minimum temperature and maximum temperature were adjusted using the average temperature delta factor.

## 8.2 HYDROLOGICAL MODELING

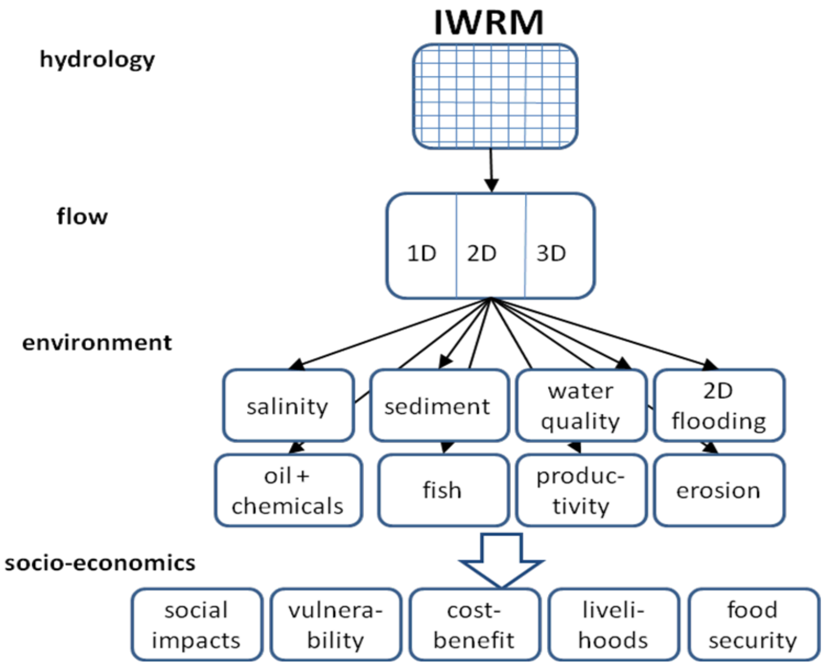
### 8.2.1 THE IWRM MODEL

Two hydrological modeling tools have been used extensively for the Mekong Basin: (i) the IWRM model; and (ii) a model suite comprising of SWAT + IQQM + ISIS. Both model suites are fully integrated into the Mekong River Commission Decision Support Framework. In addition a number of other models have been applied to subcatchments of the Mekong Basin at the national level: (i) MIKE-11; (ii) HydroGIS; and (iii) VRSAP.

The study utilized the IWRM model because it has the capacity to extend computation to coupled crop suitability and yield models. The IWRM model integrates different types of models that are usually run separately. These include hydrology, water resources allocation and management, and hydrodynamics. The modeling system can feature a large number of components (Figure A-5).

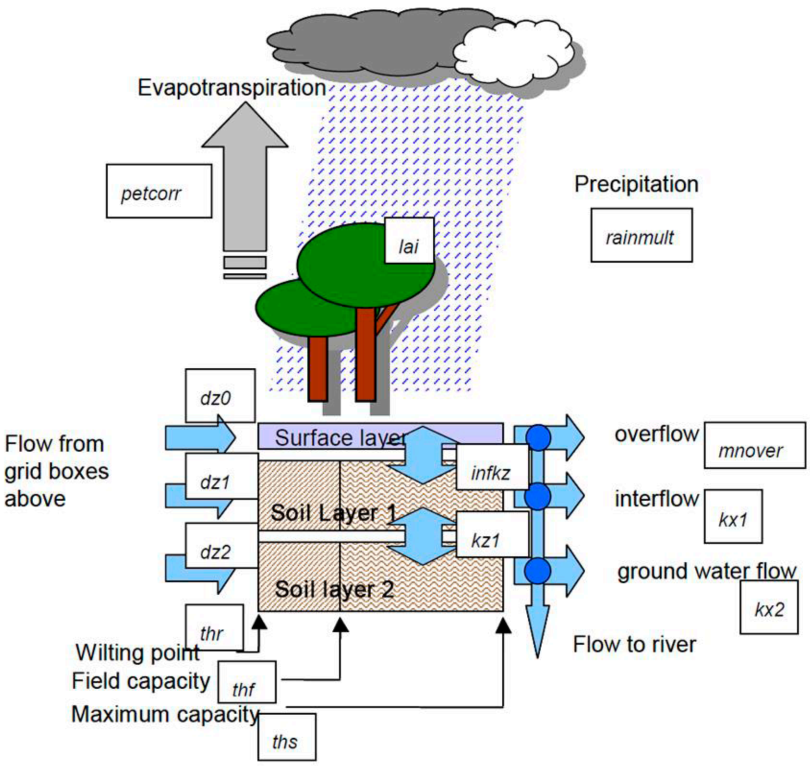
**A detailed description of the model computation methods and model equations can be found in the IWRM model manual (Koponen et al. 2010) and are summarized below.**

**Figure A-5: Assessment components of the IWRM model:** ***The IWRM model builds progressive layers of computation and complexity to assess hydrometeorological, environmental and socio-economic issues depending on the level required. Note: the socio-economic layer is not coupled with the models but is based on a GIS analysis system that utilizes model outputs.***




The IWRM is a physically based model which simulates the actual physical processes behind the Mekong hydrological regime for each grid cell in the model and for each time step under analysis based on parameters like evapotranspiration, rainfall, runoff, infiltration rate, leaf-area index, and field capacity (Figure A-6). By basing the model on the actual physical processes, it is able to accommodate changes to one or more of these parameters and quantify the impacts on the processes of the hydrological regime—making the model suitable for climate change assessments.

**Figure A-6: IWRM model computational parameters**




In the surface model, interception is first estimated using a simple storage model and vegetation leaf area index. Infiltration is computed using the Green-Ampt model and possible overflow is accumulated into pond storage and surface runoff. Evaporation is estimated using interpolated potential evaporation, pond and interception storages, soil moisture, and vegetation data in each grid cell. For surface runoff the amount of water leaving from the grid cell to the next grid cell or to a river depends on ground surface flow resistance and ground slope. The water leaving from each grid cell can continue on to a river in the grid cell or to a lower grid cell determined by the flow direction net.

Soil has been divided into two layers and the layer depths can be defined freely. The water storage of both layers is divided into two differently behaving parts and water content capacity. For flow through soil the flow amount is influenced by horizontal conductivity of the soil, ground water height and grid cell slope.

River flow computation is based on kinematic wave approximation of the St. Venant equations (flow speed depends only on slope and flow depth) with trapezoid river cross sections. The river model is solved numerically from upstream cells to downstream, so downstream surface height does not affect the upstream flows. This method enables use of a reasonably large time step and therefore shortens computation times.

Lakes are handled separately. Any set of neighboring grid cells can be set to be a lake. Each lake is a storage that keeps account of the water level as a difference from the reference water level. Water level changes are linearly related to volume changes, which are computed from inflow, outflow and lake evaporation. Outflow from the lake is computed as a function of the water height using river section equations or a given surface height/flow amount curve. Evaporation from lakes occurs at the potential rate.

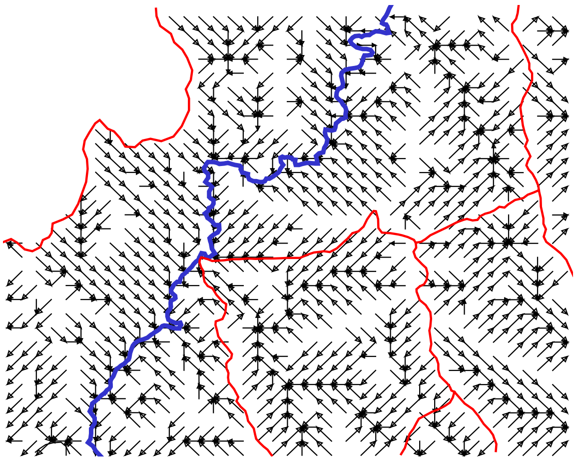
#### 8.2.1.1 Data

There are three types of input data required by the IWRM model: i) geographical data such as elevation and land cover; i) fluvial data such as flow direction, river network, and hydrology; and iii) meteorological data.

**Geographical data:** The geographical data for the IWRM model was based on a 5 km x 5 km raster dataset built from the MRC database 90 m Digital Elevation Model, Global Land Cover 2000[67], and the FAO soil map of the world[68]. Land cover and soil data were aggregated by reclassifying the landuse data to nine classes, and the soil data to eight classes.

**Hydrological data**: A 5 km x 5 km flow direction raster was computed by calculating the minimum elevation from the 5 km x 5 km DEM data (Figure A-7). The main course of the Mekong was forced into the flow direction raster by lowering the elevation model along the river's course (Lauri et al. 2012).

**Figure A-7: Part of a river network.** *Digitized river and watershed boundaries shown in blue and red, and computed flow network with black arrows.*



Hydrology data was collected for seven gaging stations along the Mekong mainstream—Chiang Saen, Luang Prabang, Vientiane, Mukdahan, Pakse, Stung Treng and Kratie. The hydrology below Kratie was not modeled using the IWRM model because below this point the river enters a broad floodplain and flow is complicated by overland and non-channelized flow. The hydrological data was obtained from the MRC database.

**Meteorological data:** Baseline and climate scenario results from the climate downscaling were used as meteorological data inputs for the IWRM model.

#### 8.2.1.2 Calibration

The model was calibrated using observed flows from 1980–2005, by comparing the model results to measured flow at the Stung Treng station. Stung Treng was selected for calibration because of data quality issues with the Kratie station.

---

[67] Global Land Cover 2000 was developed by the Land Resource Management Unit of the European Commission Joint Research Unit. The data can be purchased from http://bioval.jrc.ec.europa.eu/products/glc2000/products.php

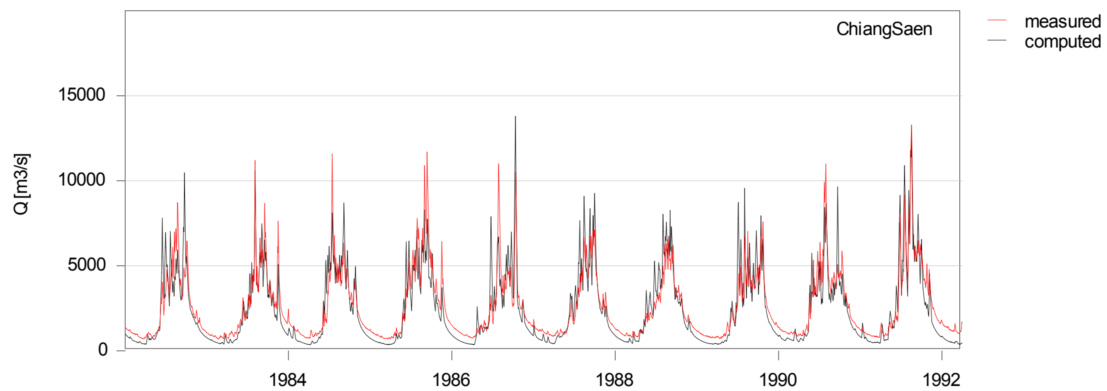
[68] The FAO soil map of the world was developed by the Food and Agriculture Organization of the United Nations. Maps can be downloaded from http://www.fao.org/geonetwork/srv/en/main.home

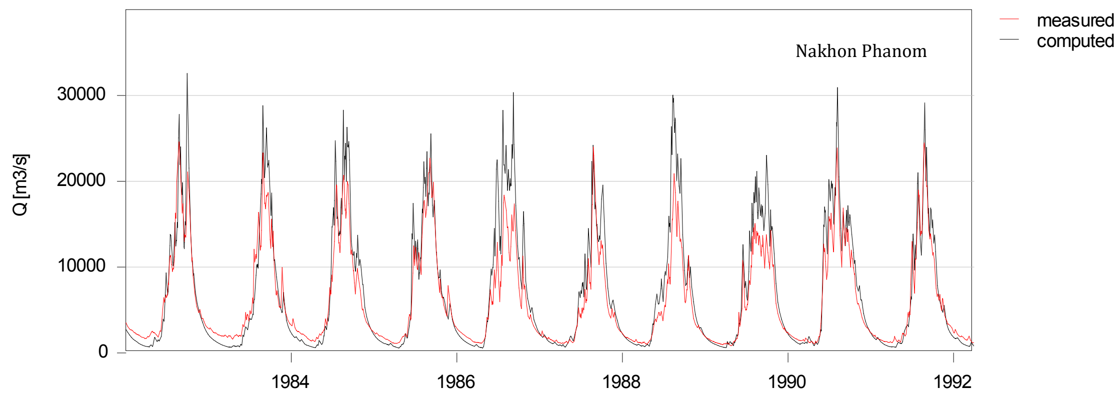
Comparison of measured and computed flows show a good correlation for all seven stations, with $r^2$ errors of between 0.77 to 0.93 (Table A-3). The model is an increasingly better fit moving downstream. At the upper part of the catchment the model underestimates dry season flows, and overestimates some peak flows (Figure A-8 Chiang Saen). Downstream the model slightly underestimates the dry season flows and overestimates flow peaks (Figure A-8 Stung Treng).

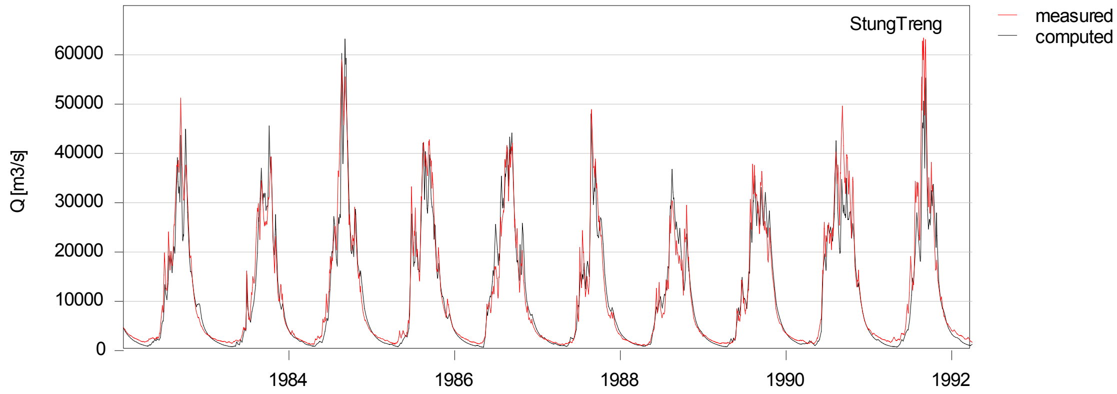
**Table A-3: Correlation between computed and measured flows (1982 to 1992) (Lauri, 2011)**

| Location | $r^2$ | Computed ($m^3/s$) | Measured ($m^3/s$) |
|---|---|---|---|
| Chiang Saen | 0.77 | 2,347 | 2,570 |
| Vientiane | 0.85 | 4,025 | 4,077 |
| Nakhon Phanom | 0.78 | 6,928 | 6,091 |
| Mukdahan | 0.87 | 7,466 | 7,025 |
| Pakse | 0.92 | 8,841 | 9,037 |
| Stung Treng | 0.93 | 11,033 | 11,788 |
| Kratie | 0.93 | 11,160 | 11,659 |

**Figure A-8: Observed (red line) and computed (black line) daily flows at (a) Chiang Saen, (b) Nakhon Phanom, and (c) Stung Treng**



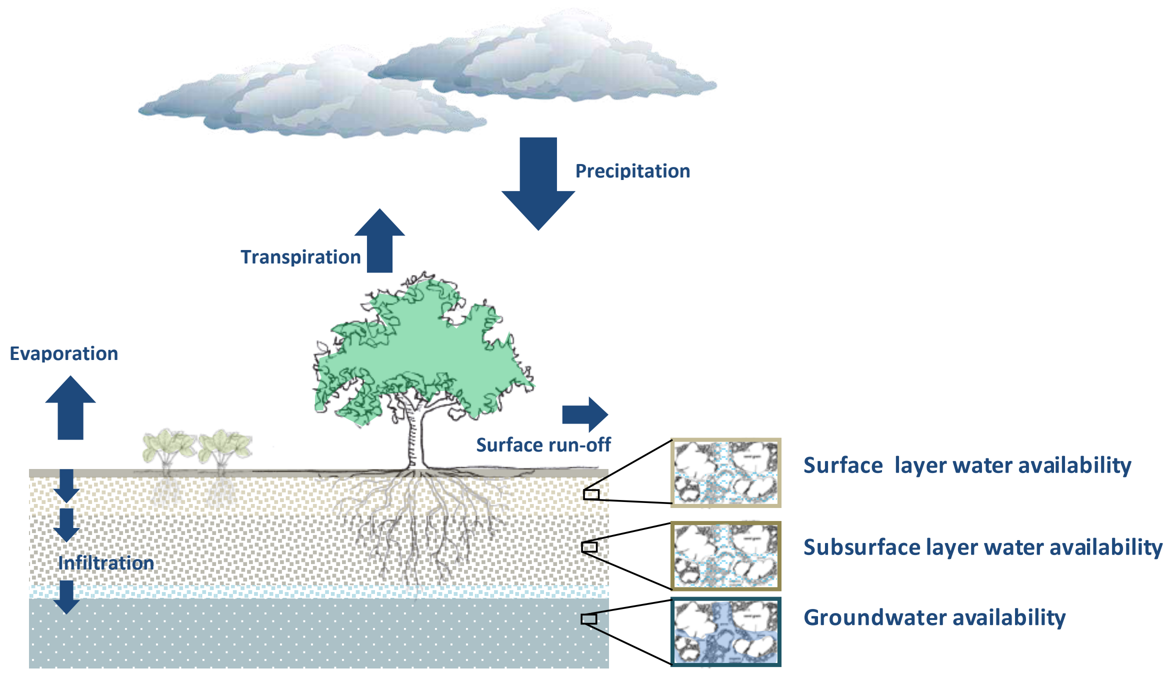



### 8.2.2 ADDITIONAL SIMULATION VARIABLES

#### 8.2.2.1 Soil water availability index

The soil water availability index is a measure of the water available in soil layers and is of direct relevance to vegetation growth. To model the soil water availability index a set of empirical equations was built into the IWRM model to calculate the water balance for each cell at each time step. The water balance was calculated as a culmination of the precipitation, evaporation, surface runoff and water available in the surface soil layer, subsurface soil layer, and groundwater (Figure A-9).

**Figure A-9: Soil water availability index components**



#### 8.2.2.2 Drought

Agricultural drought definitions interpret drought as when precipitation in a month is less than 50% of the evapotranspiration (Sys et al. 1993). This definition of drought was incorporated into the IWRM model and GIS analysis used to assess the changes in drought across the basin.

#### 8.2.2.3 Crop suitability

To evaluate the change in suitability for key crops in the LMB the study developed a module addition to the IWRM model. The module is based on the Land Use Suitability Evaluation Tool (LUSET) developed by the International Rice Research Institute (IRRI). LUSET is based on 2 input interfaces (or modules): the crop requirement module and the land unit information module (Figure A-10). For each Land Unit, the suitability of the area for growing crops is calculated using the characteristics of the land units and the crop requirements.

The land characteristics module normally includes inputs for parameters including terrain, soil, meteorology, and irrigation. For this study there is no existing survey with consistent detailed soil, terrain, or irrigation characteristics for the entire LMB therefore the analysis was limited to climate suitability—i.e., temperature and water.

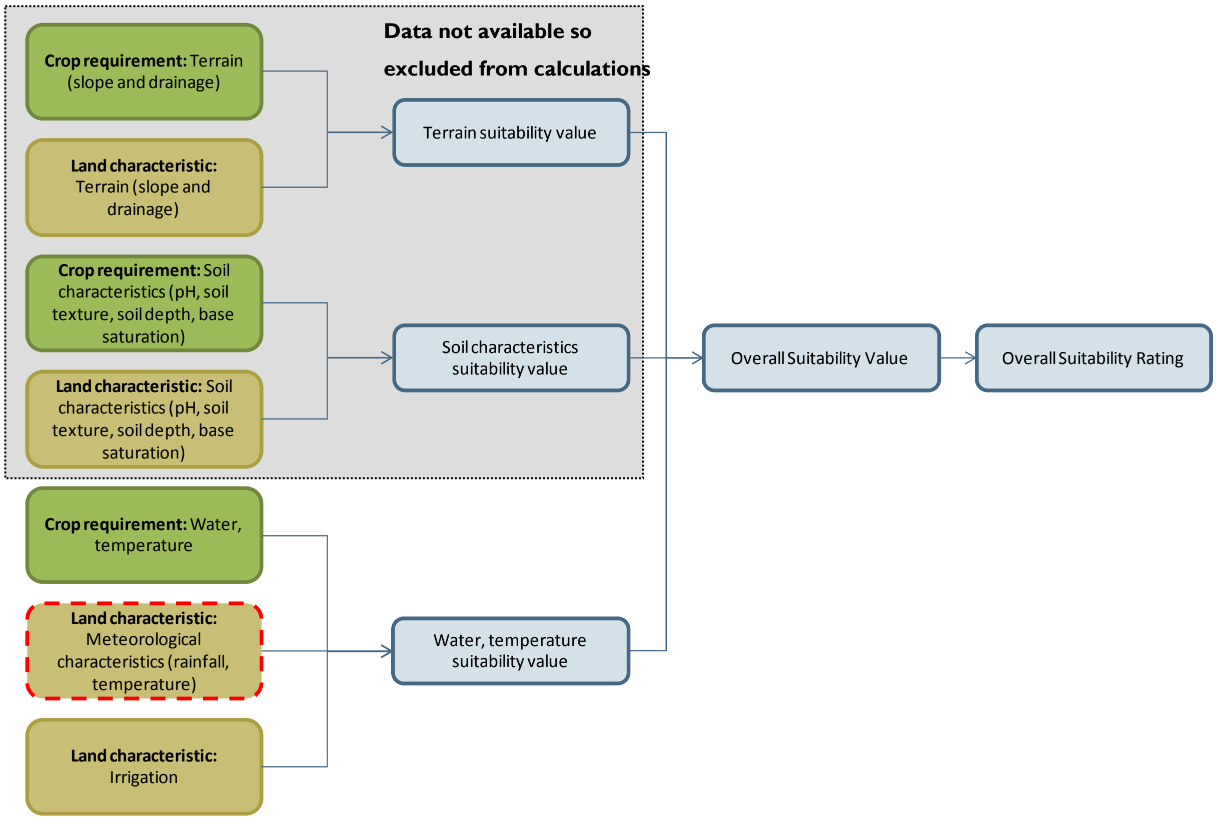
The crop requirement parameters were identified based on predefined crop requirements found in Sys et al. (1993) and modified with local expert knowledge and data from the FAO database Ecocrop.

Suitability values were calculated for each of the land unit characteristics—temperature and water. An Overall Suitability Value (combining temperature and water characteristics) was then calculated and was then transformed into an Overall Suitability Rating ranging from 1 (not suitable) to 100 (highly suitable). For spatial analysis and mapping the Overall Suitability Rating was then categorized into 7 classes of suitability (Table A-4). The output of the LUSET module consists of a table and GIS layer for each crop in which a suitability class is assigned for each grid cell.

**Table A-4: Crop suitability classes**

| Suitability Classes | Definition |
|---|---|
| **0-10: Not suitable** | The crop cannot grow or complete its life cycle |
| **10-25: Marginal suitability** | There is a high risk of crop failure |
| **25-40: Low suitability** | Crop can grow but cannot achieve an average yield due to water and/or temperature constraints |
| **40-60: Moderate** | Slight constraint of temperature or water stress and optimum yield is not achieved due to non-optimal growth conditions |
| **60-75: Good suitability** | No water or temperature stress, but optimal conditions are not achieved and crops cannot achieve maximum yield |
| **75-85: High suitability** | No climate-related stress and almost optimum climate condition throughout the cycle, leading to high yield if crop management is adequate |
| **85-100: Very high suitability** | Optimum climate condition throughout the growth cycle leading to maximum achievable yield if crop management is adequate |

**Figure A-10: LUSET model computational parameters:** *Meteorological characteristics (outlined in red) will be altered to assess impact of climate change on crop suitability. Note that detailed terrain and soil data was not available so that suitability is based solely on climate.*



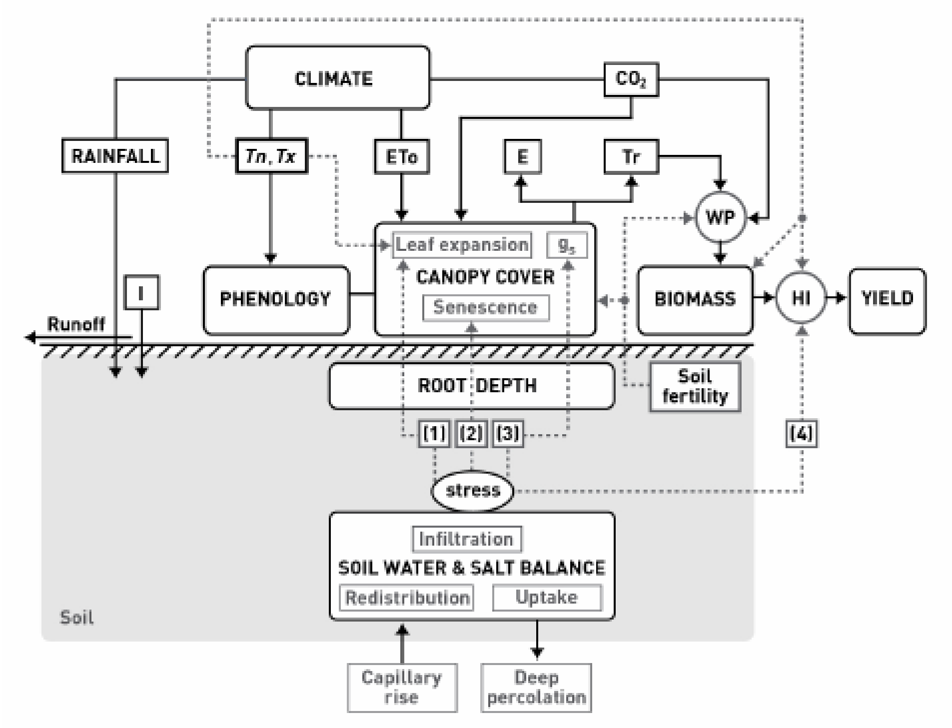

### 8.2.2.4 Crop yield

Crop yield modeling was undertaken by fully integrating the FAO AquaCrop model (FAO 2011) within the IWRM model. The AquaCrop model provides a framework and the algorithms to calculate crop yield based on climate, crop, soil, field management, and irrigation management information (Figure A-11; Raes et al. 2009). Higher resolution crop module grid cells were developed and calculated in the same way as any other IWRM grid cell with full hydrology including infiltration, soil moisture and lateral surface and soil water flow as well as the additional AquaCrop calculations.

The model used changes in daily climate data, including temperature and rainfall, to calculate changes in crop yield. Calibration was undertaken using the historical average provincial yield of the selected provinces.

Due to the computing time required for the crop yield modeling, analysis was restricted to two crops and a few provinces. Aquacrop is better suited to modeling annual rather than perennial crops. Rainfed rice and maize were identified as annual crops that are economically important and important for subsistence in the LMB. Projected change in annual yield (t/ha) for the priority provinces was modeled for each of the two crops.

**Figure A-11: FAO AquaCrop flow chart indicating the main components of the crop yield modeling (Raes et al, 2009)**




## 8.3 DELTA FLOOD MODELING

Flood modeling of the Mekong Delta was undertaken in two stages. In the first stage a MIKE 11 hydrodynamic model was used to calculate water level time series for various scenarios. In the second stage these water levels were converted to GIS layers of maximum flood depth and duration.

### 8.3.1 MIKE 11 HYDRAULIC MODEL

The study used a MIKE 11 hydrodynamic model of the Mekong Delta to quantify the changes in depth and duration of flooding and saline intrusion due to changes in upstream hydrology, sea level rise, and cyclones. The model has been used in a number of studies in the Mekong Delta (Kim et al. 2010; Huy et al. 2010; ICEM 2011; Lauri 2011).

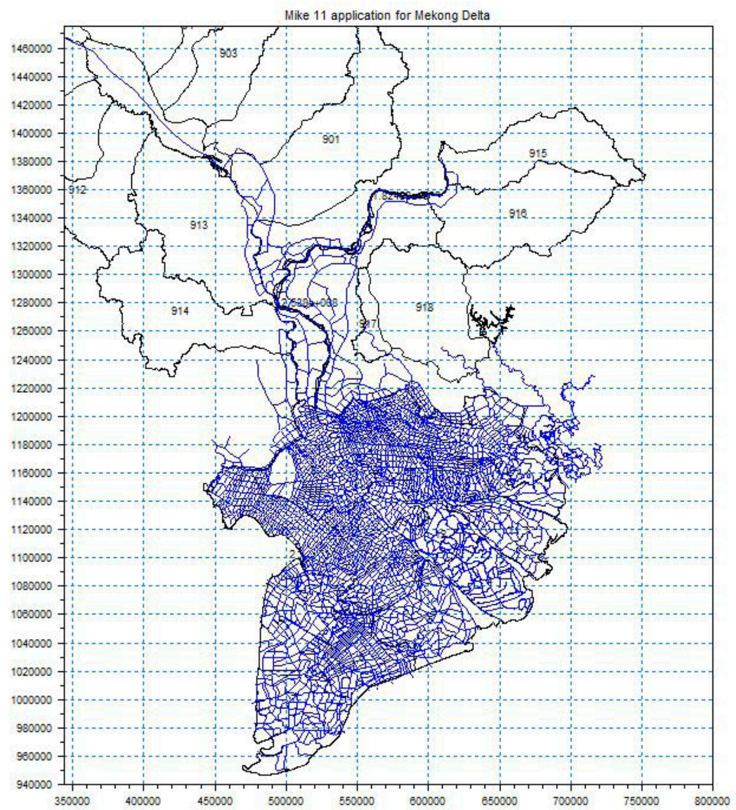
The MIKE 11 model contained detailed topographic, infrastructural, canal network, water demand, hydrometeorological, water quality, and landuse information that is combined into a hydraulic representation of the delta and Cambodian floodplains. The model's hydraulic schematization starts from Kratie, covers the floodplain in Cambodia, including the Tonle Sap system and includes the whole Mekong Delta of Vietnam (Figure A-12).

The model set up includes more than 3,900 rivers and canals and more than 5,000 hydraulic works representing irrigation and drainage sluices as well as overland flood flow to the floodplain via low-lying parts of roads. The model divides the delta into 120 zones and utilizes more than 25,900 water level and 18,500 flow points to calculate small-area water balances.

ANNEX I

Discharges from outside simulated areas in the Mekong River (upstream of Kratie) and Saigon-Dongnai river basins (upstream of Tri An hydropower station) together with tidal data for the South China Sea and the Gulf of Thailand were used as boundary conditions for the model.

**Figure A-12: The hydraulic schematization for the Mekong Delta**




### 8.3.1.1 Data

The input data for the model consists of:

- Cross sections of rivers and canal system, and distance between cross-sections;
- Digital elevation map of the modeled area;
- Present hydraulic constructions: location, dimensions, and operation schedule;
- Information on embankment status and overland flood flows;
- Hydrometeorological and water quality data: (i) tidal boundaries, (ii) water flow boundaries, (iii) irrigation boundaries, (iv) rainfall and evaporation boundaries (NAM), (v) salinity concentration boundaries, (vi) meteorological input data;
- Other input data (direct or indirect input data to model): (i) present landuse map, (ii) landuse planning, (iii) upstream development including hydropower, (iv) landuse change, (v) water management scenarios; and
- Upstream and downstream boundary conditions including Mekong flows, tidal conditions, and cyclone forcing.

### 8.3.1.2 Flood modeling scenarios

Five scenarios were selected to assess the impact of climate change on flood depth and duration and two for analyzing impacts on salinity intrusion (Table A-5). The different scenarios were implemented in the model by using different upstream and downstream boundary conditions:

- **Upstream boundary conditions** represented daily discharge data at Kratie station for each of the baseline and future climate scenarios-baseline and future hydrographs for average and 1 in 100 year flood conditions obtained from the hydrological IWRM model.
- **Downstream boundary conditions:** Analysis of historical data indicates that flooding in the delta is strongly determined by tidal fluctuations. Therefore the spring tide of 2011 was selected as the base tidal condition for each scenario. Under climate conditions a sea level rise of 0.3 m was added to the base tidal condition of 2011. For the fifth scenario cyclone forcing was also included in the downstream boundary condition.

**Table A-5: Mekong Delta flood and salinity modeling scenarios and description of boundary conditions**

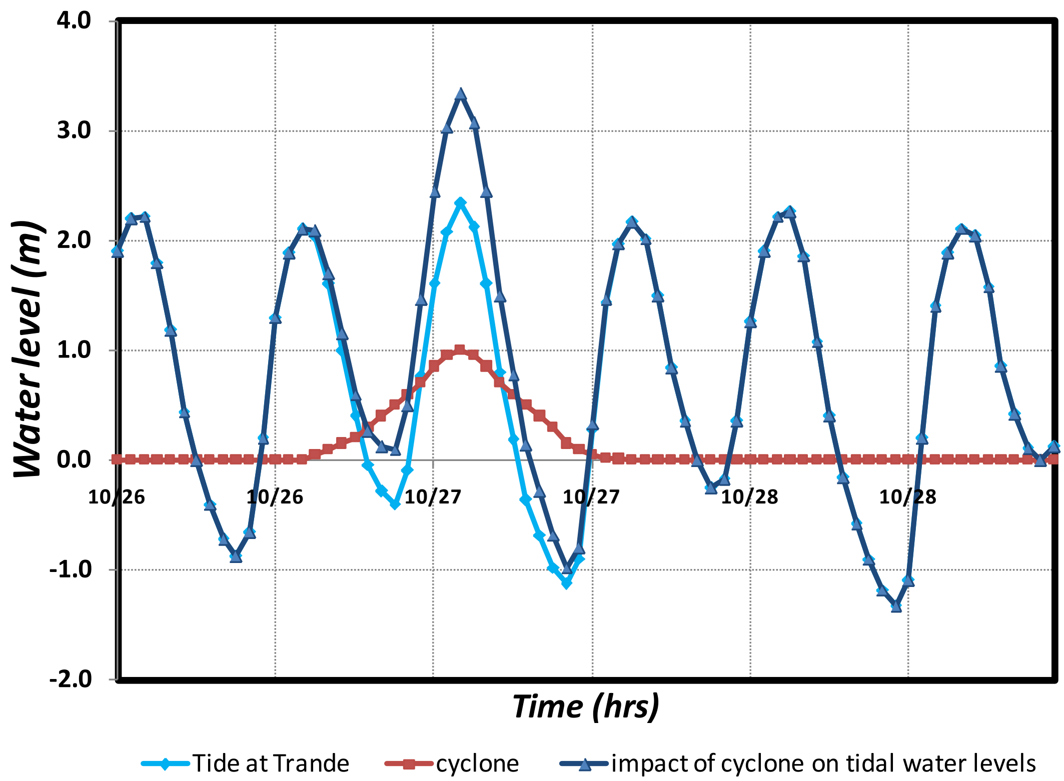
| | Scenario | | Maximum flood depth | Duration of 0.5m/1.0m depth flood | Maximum salinity concentration | Duration of 4ppt salinity concentration |
|---|---|---|---|---|---|---|
| 1 | **Baseline climate** with **average flood** | **Upstream B.C.** | *average flood (1985–2005)* | *average flood (1985–2005)* | *average flood (1985–2005)* | *average flood (1985–2005)* |
| | | **Downstream B.C.** | *2011 spring tide* | *2011 spring tide* | *2011 spring tide* | *2011 spring tide* |
| 2 | **Baseline climate** with **1 in 100yr flood** | **Upstream B.C.** | *1 in 100yr flood (1985–2005)* | *1 in 100yr flood (1985–2005)* | NA | NA |
| | | **Downstream B.C.** | *2011 spring tide* | *2011 spring tide* | NA | NA |
| 3 | **Future climate** with **average flood** and 0.3m **SLR** | **Upstream B.C.** | *average flood (2045–2069)* | *average flood (2045–2069)* | *average flood (2045–2069)* | *average flood (2045–2069)* |
| | | **Downstream B.C.** | *2011 spring tide + 0.3m SLR* | *2011 spring tide + 0.3m SLR* | *2011 spring tide + 0.3m SLR* | *2011 spring tide + 0.3m SLR* |
| 4 | **Future climate** with **1 in 100yr flood** and 0.3m **SLR** | **Upstream B.C.** | *1 in 100yr flood (2045–2069)* | *1 in 100yr flood (2045–2069)* | NA | NA |
| | | **Downstream B.C.** | *2011 spring tide + 0.3m SLR* | *2011 spring tide + 0.3m SLR* | NA | NA |
| 5 | **Future climate** with **1 in 100yr flood**, 0.3m **SLR** and **cyclone** | **Upstream B.C.** | *1 in 100yr flood (2045–2069)* | *1 in 100yr flood (2045–2069)* | NA | NA |
| | | **Downstream B.C.** | *2011 spring tide + 0.3m SLR + cyclone Linda* | *2011 spring tide + 0.3m SLR + cyclone Linda* | NA | NA |

ANNEX I

The fifth scenario included consideration of tropical cyclone impacts on the delta through the superimposition of observed data from Cyclone Linda, which hit the Mekong Delta on the 5th November 2007. Analysis of observed data from Cylone Linda indicated that the impact of the cyclone on peak water levels is strongly dependent on the timing of cyclone impact and whether this coincides with a spring tide. If a cyclone occurs during average or low tide conditions then water levels would not be out of the normal tidal range. For example during cyclone Linda the maximum water level at Bassac river mouth reached 1.90 m whereas during the spring tide of the same year the water level reached 2.08 m when no cyclone was present.

To assess the maximum affect that a cyclone may have on flooding, the study modeled the flood conditions for when the maximum increase in water level by a cyclone occurs at the exact same time as a spring tide (Figure A-13). This meant increasing the tidal forcing of the downstream boundary condition by a maximum of 1.0 m. It was assumed that only the eastern tidal boundary condition at the South China Sea was affected by the cyclone and that the western tide in the Gulf of Thailand was not affected.

**Figure A-13: Development of climate change with tropical cyclone scenario:** *Timing of cyclone impact (red line) was superimposed to coincide with spring tide conditions (light blue line) to produce peak storm surge (dark blue line) as the summation of both factors.*

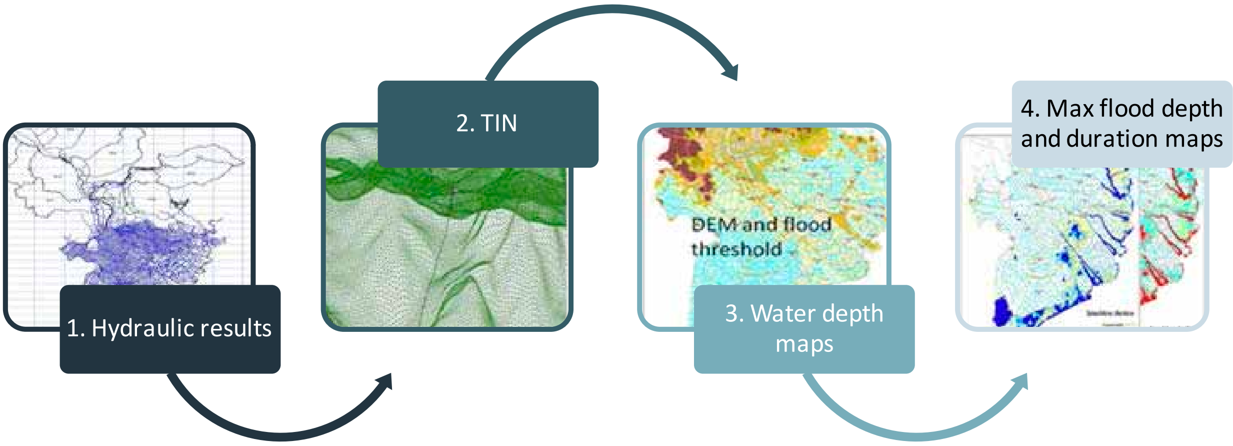


### 8.3.2 FLOOD AND SALINITY INTRUSION MAPPING

The output of the hydraulic model includes water levels at each calculated point which need to be developed into layers and overlaid on elevation to assess water depth and flood duration (Figure A-14). The process for converting the hydraulic model results to maximum flood depth and duration maps is as follows:

1. The water levels at each calculated point for each scenario were extracted from the simulated hydraulic results;
2. For each time step a TIN (Triangle Interpolation Network) was created based on the grid of simulated points;
3. The time series of TINs were overlaid on a DEM to create a water depth map for each time step; and
4. The time series of water depth maps were evaluated to identify the maximum flood depth and 0.5m or 1.0m depth flood duration for each grid cell. Based on this evaluation maps of maximum flood depth and duration were developed.

**Figure A-14: Flood mapping procedure**

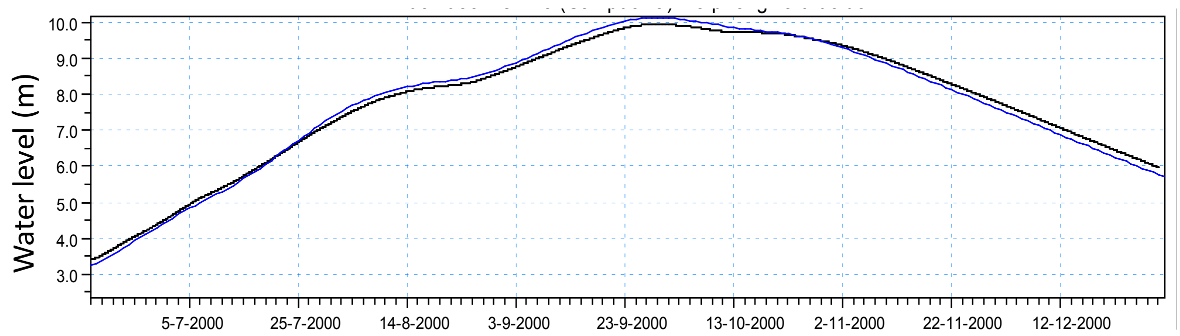


### 8.3.2.1 Calibration and validation

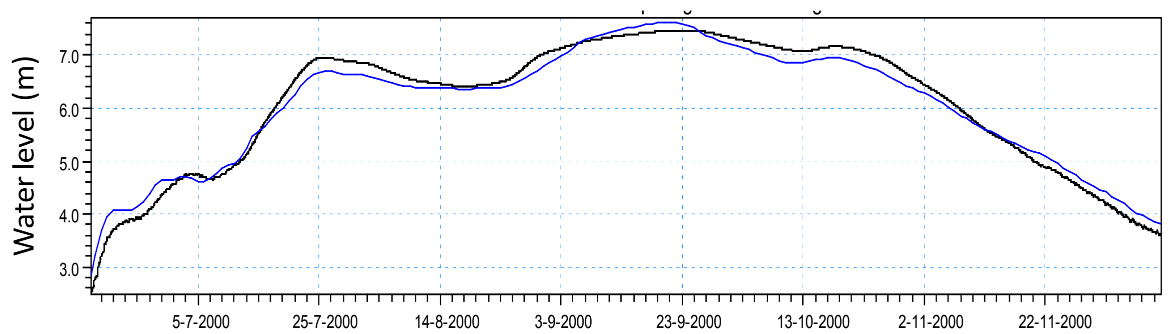
The Mike 11 hydraulic model was calibrated by comparing the modeled results to measured water levels at fifteen stations in the Cambodian floodplain and Mekong delta for the 2000 flood season.[69] Comparison of measured and computed flows shows a good correlation at all fifteen stations (a selection of station comparisons are provided in Figure A-15).

**Figure A-15: Water level calibration results of the Mike 11 flood model.**
***Note Blue line is measured data and Black line is modeled data***

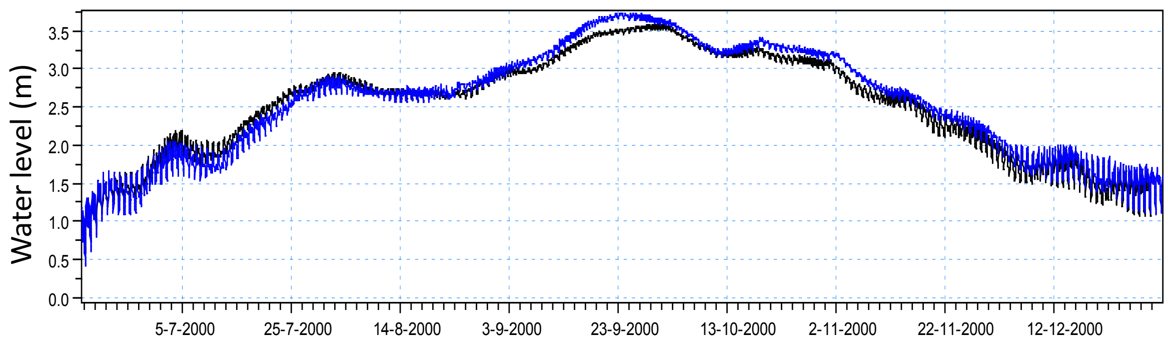
*a) Tonle Sap station*




*b) Neak Luong station, Mekong River*




*c) Vam Nao River near to Tien River – note tidal influence*

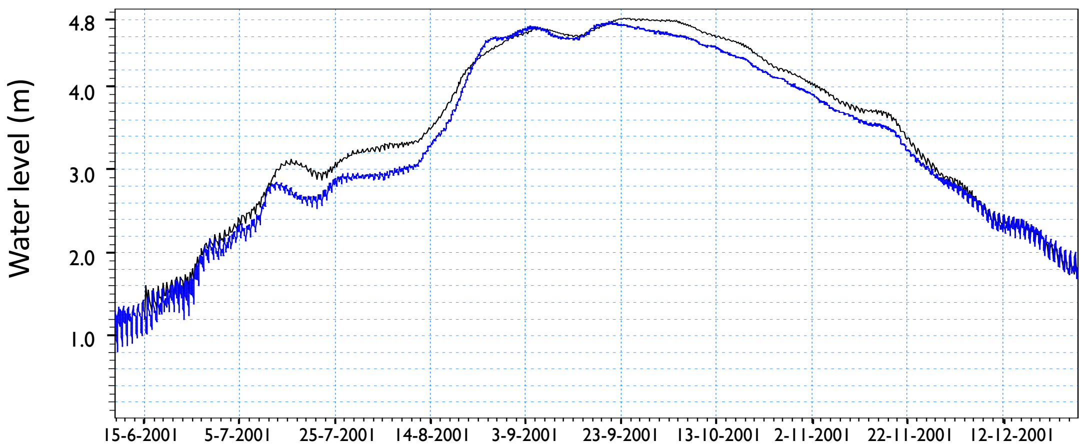



[69] Station locations include: Tonle Sap, Phnom Penh port, Neak Luong, Tan Chau (Tien River), Cao Lanh (Tien River), My Thuan (Tien River), Chau Doc (Hau River), Long Xuyen (Hau River), Can Tho (Hau River), Vam Nao (Vam Nao River), Hung Thanh, Tuyen Nhan (Vam Co River), Moc Hoa (Vam Co River), Xuan To, and Tri Ton

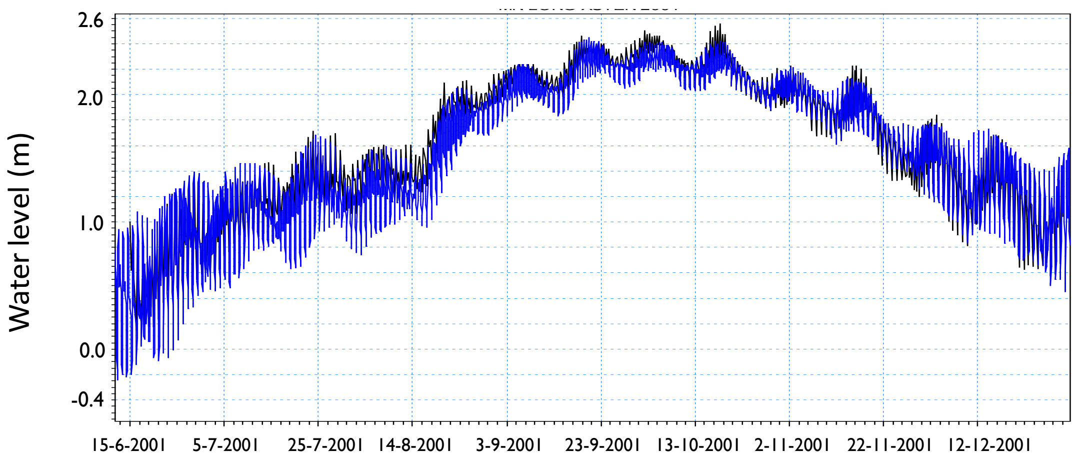
The model was validated against the 2001 flood season using measured data from six stations[70] located in the Cambodian floodplain and Mekong Delta. All stations showed a good validation of the model results (a selection of station validations are provided in Figure A-16).

**Figure A-16: Water level validation results of the Mike 11 flood model.**
***Note Blue line is measured data and Black line is modeled data***

*a) Tan Chau*




*b) Long Xuyen*




70 Station locations include: Tan Chau, Chau Doc, Long Xuyen, Can Tho, My Thuan, and Vam Nao

**U.S. Agency for International Development**
Regional Development Mission for Asia
Athenee Tower, 25th Floor
63 Wireless Road, Lumpini, Pathumwan
Bangkok 10330, Thailand
Web: http://www.usaid.gov
Facebook: http://www.facebook.com/USAIDAsia
Flickr: http://www.flickr.com/photos/usaidasia