Background Paper:

Impact of Climate Change on Water and Wetland Resources in Mekong River Basin: Directions for Preparedness and Action

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Table of Contents

Preface

The draft version of this documents was used as a background paper of the **Workshop on Impact of Climate Change on Water and Wetland Resources in Mekong River Basin: Directions for Preparedness and Action**, which was jointly organized by IUCN and SEA START RC, in Bangkok during 25-26 November 2002.

This background paper is the result from the review and excerption of many synthesis and assessment, primarily from the IPCC Third Assessment Report, Ramsar COP8 Document on Climate Change and Wetlands, and Mekong River Basin Diagnostic Study Report (MRC, 1997) as well as others. The section 2 of this document on the Potential Climate Change and Its Impacts on Mekong River Basin, which explains the impact of climate change on precipitation over the Mekong River basin and its implication on the affect on the water and wetland resources is the result from the preliminary finding of the phase 1 of the Assessment on Impact and Adaptation on Climate Change (AIACC) AS07 regional study: ***Southeast Asia Regional Vulnerability to Changing Water Resources and Extreme Hydrological due to Climate Change.***

The objective of this background paper is to set the scene on how the climate in Mekong River Basin region may change in the future, when the carbon di oxide ($CO_{2)}$, which is the major GHG, in the earth atmosphere has reached double level from nowadays, and what may happen in the region as the water resources may change as the result of climate change in the future. The results of future climate change in the region as reported in this paper are outputs from the regional climate modeling technique, not from the global model downscaling technique oftenly used in other studies.

The outcomes of different climate and hydrological models shown are only to demonstrate on how these quantitative outputs may be used to assess future impacts and vulnerability of human society to climate change. These outputs should also not to be taken as the 'predicted' climate and hydrological regimes, but they are just 'scenarios' that may or may not happen in the future as there are many other factors that needed to be taken into consideration beside just only atmospheric CO_2 level. Furthermore, the impacts on the Mekong region from future climate change and adaptation options are still a hypothetical and conceptual conclusion at this point in time. Further study in terms of assessment of impacts from climate change based on various socio-economic scenarios, which will involve more participation from many other stakeholders as well as experts in the region, will be conducted under the next phase of the AIACC AS07 study to confirm the hypothesis that is raised from this preliminary finding as well as the issues that may be raised from this workshop. Finally, the development of adaptation options to cope with such impacts will be developed under the last phase of the AIACC AS07 regional study.

The authors of this paper hope that this report as well as the workshop would help create awareness on the climate change and its impact on water and wetland resources and also help in develop a higher degree of co-operation among the policy makers, stakeholders and experts, both at the local and regional levels, for further study of the impacts from climate in greater details as well as in other dimension(s) in the Mekong region in the future.

Section 1: Background on Climate Change, Water & Wetland Resources and Mekong River Basin[1]

1.1 Introduction: Linkages Between Climate Change, Water and Wetland Resources

Changes in climate occur as a result of internal variability of the climate system and external factors (both natural factors such as solar radiation, cloud formation, and rainfall and those resulting from human activities, including increased concentrations of greenhouse gases) in the atmosphere.

Since the industrial revolution in Europe in the mid 18th century, human activities (e.g., burning fossil fuel and land use/land cover change) have increased the atmospheric greenhouse gases (e.g., water vapor, carbon dioxide, methane, nitrous oxides, and sulfur dioxide). Increase in these greenhouse gases, especially carbon dioxide, has and will continue to increase the mean global temperature, alter the precipitation patterns, and raise sea level. This will result in an enhanced global hydrological cycle and more extreme and heavier precipitation events in many areas. Atmospheric concentrations of carbon dioxide have increased by about 30% and methane by about 150% during the last one and a half century (IPCC 2001).

Other greenhouse gases and the associated biogeochemical cycles have also been affected. For example, nitrogen production, due largely to chemical fertilizer production, has doubled in the 20th century (Walker et al 1999), and atmospheric concentrations of nitrous oxide have increased by about 16% (IPCC 2001).

Changes in anthropogenic sulfur dioxide emissions have been large, but regionally variable, and the gas is generally short-lived. In the late 1990s, the anthropogenic sulfur dioxide emissions decreased compared to the mid-1980s, due to structural changes in the energy system as well as concerns about local and regional air pollution (Albriton & Filho et al 2001). These emissions, or aerosols, cool the atmosphere (unlike the other greenhouse gases), but are still important in explaining the changes in climate observed in the 20th century and those projected for the 21st century and beyond

1.1.1 Potential Climate Change Impact on Hydrological Changes

Precipitation is the main driver of variability in the water balance over space and time, and changes in precipitation have very important implications for hydrology and water resources. Hydrological variability over time in a catchment is influenced by variations in precipitation over daily, seasonal, annual, and decadal time scales. Flood frequency is affected by changes in the year-to-year variability in precipitation and by changes in short-term rainfall properties (such as storm rainfall intensity). The frequency of low or drought flows is affected primarily by changes in the seasonal distribution of precipitation, year-to-year variability, and the occurrence of prolonged droughts. There are different trends in different parts of the world, with a general increase in Northern Hemisphere mid- and high latitudes (particularly in autumn and winter) and a decrease in the tropics and subtropics in both hemispheres.

Current climate models simulate a climate change-induced increase in annual precipitation in high and mid-latitudes and most equatorial regions but a general decrease in the subtropics (Carter and Hulme, 1999), although across large parts of the world the changes associated with global warming are small compared to those resulting from natural multi-decadal variability, even

[1] Many parts of this section are excerpt, primarily, from IPCC Third Assessment Report and Mekong River Basin Diagnostic Study Report.

by the 2080s. Changes in seasonal precipitation are even more spatially variable and depend on changes in the climatology of a region. In general, the largest percentage precipitation changes over land are found in high latitudes, some equatorial regions, and Southeast Asia, although there are large differences between climate models.

In the tropics, climatic extremes are predicted to increase in their frequency and severity. Monsoons and tropical storm surges may become more intense. Increasing temperatures, changes in precipitation and evaporation, changes in river flows and runoff, and sea level rise are likely to occur. Floods and droughts are likely to increase in number as well as in severity and duration. These are among the main aspects of climate change that will affect hydrological conditions and induce hydrological changes.

1.1.2 Climate Change Impact on Inland Wetlands

Hydrology is probably the most important determinant for the establishment and maintenance of specific types of wetlands and wetland processes. Hydrologic conditions can directly modify or change chemical and physical properties, and modifications of the physicochemical environment have a direct impact on the biotic response in wetlands. Hydrologic pathways e.g. precipitation, surface runoff, groundwater, tides, flooding rivers transport energy and nutrients to and from wetlands. Water depth, flow patterns, duration and frequency of flooding influence the biochemistry of the soils and are major factors in the selection of the biota of wetlands.

> **Hydroperiod**, the seasonal pattern of the water level of a wetland, is highly significant, defining the rise and fall of a wetland's surface and subsurface water. Hydroperiod is unique to each wetland type. The constancy of hydroperiod from year to year ensures stability for a wetland.
>
> **Flood duration** (the amount of time that wetland is in standing water) and **flood frequency** (the average number of times that a wetland is flooded in a given period) are both important factors. Wetlands with long flooding durations tend to have lower species richness in vegetation than do less frequently flooded areas; waterlogged soils and the subsequent changes in oxygen content and other chemical conditions limit the number and types of rooted plants that can survive.

Hydrology leads to a unique vegetation composition but can limit or enhance species richness. Hydrology stimulates diversity when the action of water and transported sediments creates spatial heterogeneity, opening up additional ecological niches. Different species have different physiological responses to flooding. Large trees show greater tolerance to flooding than do seedlings. Plant establishment depends on the tolerance of the seeds to flooding. Plant succession depends on the geomorphic evolution of the floodplain e.g. by sediment deposition.

There is complex relationship among hydrology, nutrient inputs, wetland productivity, decomposition, export, nutrient cycling. Primary productivity in wetlands is enhanced by flowing conditions and a pulsing hydroperiod and is often depressed by stagnant conditions. Organic accumulation in wetlands is controlled by hydrology through its influence on primary productivity, decomposition, and export of particulate organic matter. Nutrient cycling and nutrient availability are both significantly influenced by the hydrologic conditions. “Openness” of a wetland to hydrological fluxes is one of the most important determinants of potential primary productivity. Wetlands in stagnant (nonflowing) or continuously deep water tend to have low productivities. Alternating wet and dry conditions may lead to optimum litter decomposition rates, while anaerobic conditions due to constant flooding are the least favorable conditions for decomposition. When productivity and decomposition rates are high, as in flowing water or pulsing hydroperiod wetlands, nutrient cycling is rapid. Hydroperiod of a wetland has significant effect on nutrient transformations and on the availability of nutrients to vegetation. Nitrogen availability is affected by the reduced conditions that result from waterlogged soil. The flooding of wetland soils, by altering pH and the redox potential of the soil, influences the availability of other nutrients. Phosphorus is known to be desorped from soil particle into solution under anaerobic conditions.

The potential impacts of climate change on wetlands are based on studies assessing the effects on wetland plant communities of climate variability and overuse of water resources. The effects generally involve the replacement of original wetland species with other types of wetland species (e.g., succession of swamp and fen peatland communities to bog peatland communities) or forest or headland species, and associated effects. Related to this, climate warming could promote the invasion of alien species and the range expansion of existing alien species.

It is thought that the response of wetland plant communities may greatly influence the species diversity of wetland ecosystems. However, the natural temporal and spatial variability of wetland communities due to variability in water supply is a key factor, and one that makes it difficult to predict impacts of climate change.

Sea level rise may affect a range of freshwater wetlands in low-lying regions. For example, in tropical regions low-lying floodplains and associated swamps could be displaced by salt water habitats due to the combined actions of sea level rise, more intense monsoon rains, and larger tidal/storm surges (Bayliss et al 1997). Such changes will result in dislocation, if not displacement, of many wetland species, both plants and animals. Plant species not tolerant to increased salinity or inundation could be eliminated whilst salt-tolerant mangrove species could expand from nearby coastal habitats.

Climate change may also affect the wetland carbon sink, although the direction of the effect is uncertain due to the number of climate-related contributing factors and the range of possible responses. Any major change to the hydrology and vegetative community of a wetland will have the potential to affect the carbon sink. The impact of water level draw-down in northern latitude peatlands has been well studied and is thought to provide some insight for climate change impacts. Vegetation changes associated with the water draw-down resulted in increased primary production, biomass, and slower decomposition of litter, such that the net carbon accumulation rate remained unchanged or even increased. However, other aspects of climate change, such as longer and more frequent droughts and thawing of permafrost, will most likely have negative effects on peat carbon balance. In addition, human activities such as agriculture and forestry will also continue to transform wetlands and reduce overall wetland area, potentially resulting in losses of stored carbon.

The extent of biodiversity loss or dislocation from inland habitats as a consequence of climate change will be difficult to discern from other existing pressures. However, it can be assumed that large-scale change to these habitats will result in species changes. Vegetation zones, such as those in high latitudes and altitudes, and presence of species may change in response to temperature and inundation patterns. The extent of such change is unknown. Some fish migrations may also be affected by both temperature and flow patterns.

The most apparent faunal changes may occur with migratory and nomadic bird species that use a network of wetland habitats across or within continents, respectively. The cross-continental migration of many birds is at risk of being disrupted due to changes in habitats (see references in Walther et al 2002). Disruption of rainfall and flooding patterns across large areas of arid land will similarly adversely affect bird species that rely on a network of wetlands and lakes that are alternately or even episodically wet and fresh and drier and saline (Roshier et al 2001).

Responses to these climate-induced changes may also be affected by adaptation and mitigation actions that cause further fragmentation of habitats or disruption or loss of migration corridors, or even by changes to other biota, such as increased exposure of wading birds to predators (Butler and Vennesland 2000).

1.2 Mekong River Basin

1.2.1 Physiography

For the Purpose of this study, the Mekong River Basin (MRB) is divided into the following five principal landform divisions as modified from MRC Diagnostic Study (2001).

- Lancang River Basin (Yunnan) ;
- Northern Highlands (Lao PDR, Myanmar, PRC (Yunnan), Thailand) ;
- Korat Plateau (Thailand) and Sakon Plateau (Lao PDR) ;
- Eastern Highlands (Lao PDR, Vietnam) ; and
- Southern Lowlands (Cambodia, Lao PDR, Vietnam) which also include small upland area in the southwest part of Cambodia

Each of these landforms has specific development opportunities and constrains.

Mekong River Basin landform division

1.2.1.1 Lancang River Basin (LB)

The Lancang River (as the Mekong called in China) runs through the Hengguanshan Mountain System with the highest peak (Kagebo peak) at 6,740 m and the lowest point at Simao port, at 317 m. The North of the Lanchang River Valley is parallel to the Gaoligonshan and Rushan Mountains and the Yunling Mountains. According for about 15% of the LRB, the Northern part is characterized by high mountains from 3,500-5,000 m and valleys above 2,000 m.

The central part (72% of the LB) consists of medium-sized mountains and wide valleys at elevations of 1,000 to 3,000 m, with high levels of soil erosion. The central portion is the most populated, with agricultural, industrial, and urban developments located primarily in the Lanchang's tributaries.

The Southern part (13% of LB) is characterized by medium and low mountains and valleys below 1,000 m, with small population centers scattered along the mainstream and limited arable land.

1.2.1.2 Northern Highlands (NH)

the Northern Highlands extends over Southern Yunnan, Myanmar, Northern Thailand, and Northern Laos. The Mekong Valley and its tributaries are deeply enroded, with slopes exceeding more than 30 %, due to both natural and man-made actions. The valley floors are generally more than 600 m below the mountain crests, extending up to 2,800 m. The extreme topography hosts a sparse population with agriculture limited to rice crops on the narrowvalley floors and shifting cultivation on the mountainsides.

1.2.1.3 Korat and Sakon Plateaus (KP)

The Korat and Sakon Plateaus, which extended over Northeastern Thailand and the floodpains of Southern Laos, are surrounded by the Northern and Eastern Highlands in Laos and the Petchabun and Phnom Dangrek Ranges in Thailand and Northern Cambodia. The Nam Mun and its major tributary, the Nam Chi (together known as Mun-Chi), in Northeastern Thailand draind more than half of the Korat Plateau. The low gradients of the Nam Songkram and Num Mun in the North trend to delay the evacuation of monsoon rainwater causing drainage problems and leading to floods. the Sakon plateau is drained by tributaries originating in the Northern and Eastern Highlands, e.g., the Nam Ngum and Nam Lik.

The flatlands of the Korat and Sakon Plateaus have hosted a large agrarian population. Te Plateaus also have a high potential for agriculture development through flood control, drainage, irrigation, and measures to reduce salinization.

1.2.1.4 Eastern Highlands (EH)

The Eastern Highlands span 50-300 km and extend down the mountain ranges of Eastern Laos and Central Viet Nam. The two main tributaries leading from the Eastern Highlands are the Nam Ca Ding (including the Nam Theun) and the Upper Se Bang Fai. The area is still sparsely populated.

1.2.1.5 Lowlands (LL)

The true lowlands extend from the Korat Plateau and Khone Falls, through Cambodia and the Viet Nam Delta. After passing the last rapids at Sambor, the Mekong River traverses a series of levees and empties into the Mekong floodplain, extending downstream from Kompong Cham to the Delta in Viet Nam. The floodplain could has the depth range between 0 to 7 meters over a year.

The Tonle Sap River that link the Great Lake with the mainstream reverses direction during the flood season and acts as a natural flood regulator for southern Cambodia and the Viet Nam Delta by decreasing flood peak during the high flow season and increasing low flow in the dry season. During the dry season, the Tonle Sao River drains the Lake towards its confluence with the Mekong River, supplementing the low Mekong flow by about 16 percent. From mid-May to early October, however, the flow of the Mekong – Bassac system becomes so great that the Delta cannot support the volume. Rather than flooding its banks, the water of the Mekong reverses flow up the Tonle Sap River to fill the Great Lake and is surrounding swamp forests. The Great lake, the greatest inland water body in Southeast Asia and the main feature of the Lowlands, covers an area of 250,000-300,000 ha in the dry season and 1,300,000 ha in the west season, extending over 300 km from the Northwest to the Mekong River at Phnom Penh.

Just below the confluence of the Tonle Sap Rivers near Phnom Penh, the main river divides into the Bassac and Mekong Rivers for its outflow through the Mekong Delta, which covers 49,520 km^2 , 74% of it in Viet Nam.

With the most fertile agricultural land, the lowlands have historically been the most densely populated. However, acid-sulfate soils and saltwater intrusion present constraints to expansion of agricultural output.

The Southern Uplands, made up of the Cardomonm and Elephant Ranges, separate the Lowlands from the Gulf of Thailand. The catchments in the Cardomom Range drain into the Great Lake and Tonle Sap River. The Prek Thnot River in the Elephant Range drains into the Bassac River. Population in this area is sparse, but mining in the Cardamon Range has caused some environmental damage.

The coastal area of the MRB has inmate geographical and ecological linkages to the inner zone of the Delta. Examples of these linkages include the issues of sediment loading, subsidence and sea–level rise of the coastal region, the vitally important economical and ecological roles of the coastal zone, and the problems of acid-sulfate soils and salinity intrusion.

Summary: Key characteristics of MRB landforms

Landforms	Rainfall (mm/year)	Vegetation	Pop. Density (pers-km^2)	Chief economic activity	Problems
Lancang River Basin (LB)	Variable: 600-2,700	Mountain brush, meadow, pine forest, mixed evergreen & broad-leaved, arable land	Low to moderate: 7-145	Argiculture (frequently shifting)	Erosion, forest degradation, natural disaster
Northern Highland (NH)	Wet: 2,000-2,800	Grassland, hill evergreen and mountain forest	Low: 8-15	Argiculture (frequently shifting)	Erosion, forest degradation
Korat & Sakon Plateau (KP)	Relatively dry: 1,000-1,600	Scrub, grassland, arable land	Moderate: 80-160	Argiculture (irrigated and rainfed)	Limited wate resources, floods and drought, salinization, low fertility
Eastern Highlands (EH)	Wet: 2,000-3,200	Upland savannah, rain forest	Low: 6-33	Argiculture (shifting)	Erosion, soil degradation, forest degradation
Lowlands (LL)	Variable: 1,100-2,400	Arable lowland and dense upland	Moderate to dense in Lowlands: 10-570 Very low in Upland: less than 8	Argiculture in Lowlands(rice cultivation) Small development in Upland	Flooding, acid-surfate soils, salinity instrusion, drought in Lowland Forest degradation in Upland

1.2.2 Climate in Mekong River Basin

The MRB hosts seven climatic zones from tropical to frigid-temperate.

The tropical climate of most of the MRB is characterized by two monsoons from the southwest and the northeast and occasional periods of cold weather by the high pressures from Siberia and China.

- o Rainy season that cover the southwest monsoon and the second inter-monsoon transition periods. The season is charactized by heavy and frequent rains, high humidity, cloudiness, and high temperatures. A short drought period is typically encountered for 1-2 weeks in high latitude part and 1-2 months in the low latitude part of the MRB.

- o Cold season that covers the northeast monsoon. This season is characterzed by little precipitation, low humidity, minimal cloudiness, and the lowest annual temperatures.

- o Summer season, that cover the first inter-monsoon transition period, is characterized by increasing preciptation, cloudiness, and humidity.

Monsoon seasons of the MRB

<table>
<tr><td colspan="2">Cold Season</td><td colspan="3">Summer Season</td><td colspan="5">Rainy Season</td><td colspan="2">Cold Season</td></tr>
<tr><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Oct</td><td>Nov</td><td>Dec</td></tr>
<tr><td colspan="2">Northeast Monsoon</td><td colspan="3">First Transition</td><td colspan="4">Southwest Monsoon</td><td>Second Transition</td><td colspan="2">Northeast Monsoon</td></tr>
</table>

Mean annual precipitation in the LMB is 1,672 mm. In China and in Northeastern Thailand it is 1,000 mm/yr. Highest precipitation levels are up to 4,000mm/yr in the Truong Son Mountains in the Eastern Highlands. Over 80-90% of annual rainfall is received from May to October, with July typically having the most rain.

1.2.3 Surface Water Hydrology

The MRB covers a catchments area of approximately 795,00 km^2 (21^{st} largest river basin in the world) and produces a total runoff of 475,000 million m^3 annually (8^{th} in the world).

As the longest river in Southeast Asia and the twelfth longest in the world, the Mekong River flows for approximately 4,880 km from its source at 5,550 metrs above sea level in the Northeast rim of the Tibetan Plateau. The Mekong flows in China for 2,161 km through the provinces of Qinghai, Tibet and Yunnan, and travels another 2,719 km through Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam before reaching the South China Sea.

Approximate figures of MRB water resources

Description	Territory						
	Yun	Mya	Lao	Tha	Cam	Vie	MRB
Catchment area (km2)	147,000	24,000	202,000	184,000	155,000	65,000	777,000
Catchment area as % of nation/province	38%	4%	97%	36%	86%	20%	--
Catchment area as % of total MRB	22%	3%	25%	23%	19%	8%	100%
Annual flow (million m3)	76,000	10,000	166,000	81,000	89,000	53,000	475,000
Average flow (m3/s) from area	2,410	300	5,270	2,560	2,820	1,660	15,060
Average flow as % of total MRB	16%	2%	35%	18%	18%	11%	100%

Source : Mekong River Commission

The hydrological regime of the Mekong River is primarily dependent on the climatic conditions of the alternating wet and dry monsoon seasons. These create major differences between flow levels, especially in the Lowlands. The high water period lasts from September to November;the low water period from February to April. The flood season in the mainstream and tributaries, from June-July to November-December accounts for 85-90% of the total annual water volume. The peak month of September accounts for 20-30% of the annual flow. In comparison, the monthly flow in the dry season accounts for dry season, the reduced flow hinders agriculture and navigation.

The annual flow of the Mekong River at some of the major hydrology station is 10,100 m^3/sec at Pakse, 13,700 m^3/sec at Kratie, 14,600 m^3/sec at Lower Phnom Penh and 14,200 m^3/sec at Tan Chau and Chau Doc.

1.2.4 Water Usage in Mekong River Basin – an indicator

Although water is abundant in almost the entire MRB, water supply is increasingly problematic due to the fact that water sources close to user do not have suitable quality: either is polluted, or has a high acidity or salinity. Also, water is not evenly distributed year-round. During the dry season, many people in the northeastern Thailand, the central highlands of Viet Nam and even in the Delta in Cambodia and Viet Nam have to walk long distances to fresh water.

Water supply, demand and withdrawals

Description	Cambodia	Lao PDR	Thailand	Viet Nam
Renewable internal water (Bm^3/year)	88	270	110	376
River inflow (Bm^3/year)	410	--	69	463
Total demand (Bm^3/year)	0.5	1.0	31.9	28.9
Internal supply (m^3/pers)	10,040	60,420	1,960	5,410
Water demand (m^3/pers)	67	259	606	416
Domestic (%)	5	8	4	13
Industrial use (%)	1	10	6	9
Agriculture use (%)	94	82	90	78

Source: MRC - Mekong River Basin Diagnostic Study
Note: Viet Nam data is for 1992; other country data are for 1987

1.3 Wetlands of the Mekong River Basin: Types, extent and distribution

Lowlands in the Mekong valleys and of the Mekong tributaries and large portion of the flat and low-lying areas in the lower Mekong River basin are wetlands, providing water, wetland resources, functions and services vital to daily life of the approximate 65 million inhabitants within the Mekong River system.

The Mekong River Basin is comprised of wetlands of various types, including perennial and seasonal, fast-flowing and slow-flowing rivers and streams; caves and waterfalls; riverine rapids and deep pools; riverine banks, beaches, bars and rocks; seasonally and permanently flooded/inundated riverine forests; riverine floodplains; seasonally and permanently inundated ponds, lakes, and reservoirs; seasonal and permanent marshes, swamps and backswamps; seasonal and permanent floodplain grassland and ricefields; estuarine and coastal mangroves; estuarine and marine inter-tidal mudflats; aquaculture; and salt works (Lacoursiere et al., 1998; Dubois, 2000).

Wetland types and areas within the lower Mekong corridor (ca. 50 km on each side of the mainstream).

Country	Wetland type	Area (ha)	Total wetland area (ha)
Lao PDR	RR1a : pool in perennial river	2,886	
	RF1 : natural floodplain grassland	7,254	
	RF1ma : floodplain wet rice	770,051	
	RF2 : natural seasonally flooded trees/shrubs	59,358	
	LL1 : natural permanent freshwater lake	12,934	
	LL1m : man-made permanent reservoir	83,376	
	PPa : permanently flooded grassland	541	
	PPb : permanent freshwater marsh with trees/shrubs	27,209	
	PSa : natural seasonally flooded grassland	1,404	
	PSc : natural seasonally flooded swamp	20	965,133
Thailand	RR1c : perennial river with perennial rapid	81,794	
	RB : riverine banks/beaches/bars	1,901	
	RF1ma : floodplain wet rice	770,593	
	RF2 : natural seasonally flooded trees/shrubs	55,774	
	RF5 : natural seasonal backswamp/marsh	14,892	
	LL1 : natural permanent freshwater lake	18,522	
	LL1m : man-made permanent reservoir	32,026	
	LL2 : natural seasonal freshwater lake	9,651	985,153
Vietnam	MS : subtidal marine/coastal	1,040,660	
	EI1b : natural intertidal estuarine cliff	18,530	
	EI1ma : artificial intertidal estuarine saltwork	3,290	
	EI1mb : artificial intertidal estuarine aquaculture	126,220	
	EI2d : estuarine mangrove swamp	123,670	
	RR : river	134,420	

Country	Wetland type	Area (ha)	Total wetland area (ha)
	RF1ma : floodplain wet rice	2,123,330	
	PSa : natural seasonally flooded grassland	400,260	
	PSc : natural seasonally flooded swamp	122,790	4,093,170
TOTAL			6,043,456

Source : MRC-IMW-LMB, 1993; MRC, 1998; Dubois, 2000.

1.3.1 Functions and Values of Wetlands

Wetlands are closely linked with the economic well-being and ecological balance in the Mekong River basin. Wetlands are valuable resources that supply many goods and services (or products, functions and attributes) to people (Finlayson 1996). These goods and services include food, fibre (e.g., reeds), clean water, carbon and other nutrient stores/sinks, flood and storm control, ground water recharge and discharge, pollution control, organic matter or sediment export, routes for animal and plant migration, landscape and waterscape connectivity. Costanza et al. (1997) estimated the total global value of these goods and services provided by coastal areas and inland wetland ecosystems to be US$15.5 trillion or some 46% of the estimated total value of goods and services provided by all ecosystems worldwide.

Other ecosystem functions are primary and secondary production, animal and plant interaction (e.g., pollination, herbivory), and carrier functions which include connectivity (landscape and waterscape), routes for animal migration, plant dispersal (including seeds), maintenance of biodiversity and aesthetic, spiritual, cultural and recreational services.

Wetland functions, and hence the goods and services provided by wetlands, will be impacted by climate change. For example, wetlands are critically important in global biogeochemical cycling (Sahagian & Melack 1998); but climate change will impact the biogeochemical cycling by affecting the hydrology, net primary production, respiration and decomposition rates and so also carbon and nitrogen cycling in wetlands.

Many wetlands contain large stores of carbon, so the release, maintenance or enhancement of these stores under a changing climate will in turn potentially affect future climate change (IPCC 2001c). Maintenance of the ecological character of a wetland (and thus its hydrological, biogeochemical, and ecological functions) will enable people to continue to enjoy the values and benefits derived from the wetland. Hence managing wetlands under climate change can support the delivery of the wise use principles of the Ramsar Convention (Davis 1994) and contribute to sustainable development of wetlands, both locally and further afield.

1.3.1.1 Wetlands and Ecological Functions

Wetlands provide significantly environmental benefits. Important wetland functions include water storage, groundwater recharge and discharge, storm protection, flood buffering and control, shoreline stabilization, erosion control, and retention of carbon, nutrients, sediments and toxicants, and regulation of local and global climates (Dugan, 1990).

The Mekong River Basin produces a total runoff of 475,000 million m^3 annually (Mekong River Commission, 1997). The annual inundation helps sustain and recharge the majority of wetlands. In dry season and in drought year, wetlands are among the principal sources of groundwater recharge. They provide water supply to communities and sanctuary to a variety of wildlife, some of which are rare and endangered species.

> Marshes and swamps tend to reduce the flows as a combined result of their storage capacity and the resistance that flood waters encounter while flowing through marshes and marginal vegetation of swamps. They thus contribute to downstream flood protection.
>
> Annual flooding dominates the biotic production of wetlands by releasing nutrients from the soil, vegetation and inundated organic debris. Water, thus enriched, supports a bloom of plankton, fish and macro-vegetation. Fish populations utilize inundated habitats like flooded forest for reproduction and replenishment of fish stocks. The nutrient rich sediments are also transported downstream to inundation plains in the Mekong delta where they are deposited in fields and swamps and in adjacent estuarine waters.

Mangrove forests help build up land by trapping sediment, expanding outwards to the sea in a natural process of land reclamation and protect coastal areas and interland from wave erosion and typhoons.

The *Melaleuca* forest ecosystems help prevent acidification of the top soil and surface water; reducing water velocity during flood season, thus minimizing flood damage; helping in sedimentation and storage of silt in the area, enriching soil fertility; maintaining suitable micro-climates which are also favorable to surrounding areas (Mekong River Commission, 1997).

The estuaries in the Mekong Delta maintain important ecological processes such as transport of nutrients, plankton, shrimp and fish larvae, and detritus – all essential components in aquatic food webs.

1.3.1.2 Wetlands and Biodiversity

Wetlands of the Mekong River Basin are unique ecosystems, exceptionally rich in biodiversity and are habitats for a wide range of globally threatened species, providing water and primary productivity upon which numerous species of plants and animals depend for survival. Wetland ecosystems support high concentrations of birds, mammals, reptiles, amphibians, fish and invertebrate species.

Wetlands are an important storehouse of plant genetic materials. A wide range of floral species are found in wetlands, including rice, the staple food of more than half of the world's population. Wild rice in wetlands is an important source of new genetic materials in developing disease-resistant and higher-yield strains. The flooded forest is central to the overall ecology of the Great Lake and Tonle Sap River system in Cambodia and to its biological productivity. Over 140 species of floodplain plants and over 60 species of mixed scrubland can be found in the inundated forest around Tonle Sap Lake (Parr et al., 1996). The flora of the Plain of Reeds in Cambodia and Vietnam is uniquely complex due to the high variety of flood and water availability regimes.

1.3.1.3 Wetlands and Sustainable/Subsistent Livelihoods

The Mekong River and its associated wetlands have, for thousands of years, supported the subsistent economy and the wellbeing of many millions of people. Wetland ecosystems provide direct and indirect benefits – which may be tangible or intangible – to people living in the vicinity. Wetlands provide “products” which are the basic needs, augmenting the diet, curing the sickness, providing housing materials, and enhancing the occupation and income of rural and urban inhabitants of the Mekong River Basin.

Wetlands are major source of **water supply** for rural households. Domestic, agricultural and industrial sectors rely on surface and underground water withdrawals. Demand for fresh and clean water is expected to grow considerably and competition for freshwater resources is likely to be a problem in the Mekong countries for the foreseeable future.

Rice, which is a staple food in all the Mekong countries and major export of countries like Thailand and Vietnam, is grown in wetlands. The Mekong Delta provides 50% of Vietnam's total rice production.

Livestock and poultry production also depends on wetlands.

Wetlands are major sources of low-cost but high quality animal protein. **Fish and aquatic animals** are major daily protein intake in the diet – over 80% in Cambodia (Mekong River Commission, 2001), 70-90% in Lao PDR (ICLARM, 1999), and over 60% in Thailand (Choowaew et al., 1994). Consumption of fish and aquatic animals is estimated at 20-35, 30-50, and 20-60 kg per capita per year in Thailand, Cambodia and Vietnam respectively (ICLARM, 1999).

Wetland **wildlife** such as several species of frogs, snakes, turtles, tortoises and terrapins and soft-shelled turtles, freshwater stingrays, molluscs, crabs, insects and birds are important sources of supplementary protein, and are not only consumed domestically but also sold in local markets providing an additional household income source. Amphibians, reptiles and birds are vital to agro-ecosystems and to rural economy in the basin as they play an important role in rodent and insect control. Some animals such as crocodiles and snakes are also exploited for food and skins.

Aquatic plants and vegetables are harvested for food as well as for traditional medical purposes. Several kinds of aquatic plants are grown in wetlands for animal feed and for sale. Through the harvest and sale of wetland produce such as morning glory *Ipomoea aquatica,* duckweed *Lemna sp.,* and water hyacinth *Eichhornia crassipes*, wetlands also provide daily income and economic opportunities for many unemployed and the under-employed inhabitants.

Wetlands provide **fibre and wood** for fencing and housing materials as well as **raw materials** for cottage industries, matting and handicrafts, and compost. Mangrove forests provide construction timber and charcoal, particularly *Rhizophora sp.* with high calorific value and little smoke, and other products such as tannin, *Nypa fruticans* leaves for thaches. The *Melaleuca* forest ecosystems provide *Melaleuca leucadendron* timber for construction which is valuable due to its strength, durability and resistance to insect and fungi attacks, and other products such as capejut oil, honey, fibers from creeper plants (such as *Stenochlaena palusstris)* for making ropes, and fibers from emergent aquatic plants like *Lepironia sp.* for making mats.

The Mekong River and its associated wetlands support one of the largest inland **fisheries** in the world. The fisheries sector makes a significant contribution to the rural economy in all Mekong countries. Fish and other aquatic resources generate a significant source of occupation and income. The majority of rural families are either part- or full-time fishermen or fish farmers. The total annual catch of the Lower Mekong River Basin (Cambodia, Lao PDR, Thailand and Vietnam) alone is estimated at 1.6-1.8 million metric tons which is a value of approximately over 1.4 billion US dollars (Mekong River Commission, 2001).

For a landlocked country like Lao PDR, the Mekong River is the lifeline and is also an important means of **transportation**.

The Tonle Sap river and the Great Lake, in the context of **tourism**, provide attractive cruises to Siem Reap and the famous Angkor Wat temple complex of Cambodia.

1.3.2 Present Uses and Management of Wetlands

Uses of wetlands differ according to wetland types and sizes. The Great Lake of Cambodia is intensively used for fisheries. The Mekong Delta of Vietnam is intensively used for rice production. Both cases contribute substantially to the national and local economies. Uses of many other wetlands in the Mekong River Basin are of marginal value but for significantly subsistent livelihoods of the basin's inhabitants.

Marshes and swamps are used for agriculture, in the seasonally inundated peripheral areas, and for fisheries in the central perennially-inundated areas. Harvesting of natural products such as wood, edible plants, plants of medicinal value, and utilizing peripheral areas for grazing, livestock and cattle, besides being habitats for animals and birds, are uses made of wetlands.

Flooded forest in northeastern Thailand is public land traditionally used all year round for over 100 years for rice planting (from January to August for lowland rice, from February to September for upland rice), cultivating upland crops (February –August), growing vegetables (December-January), firewood collection (January-September), animal rearing during dry season, and wild products gathering throughout the year. Mushrooms are collected between late April-May to September (5 months). ManSang starts growing from late April-May and is collected for domestic food and sale in August-September. Rattan is harvested during January-April. Reeds is collected between February-April. Fruits and bamboo shoots are collected in 3 months during May-August. Medicinal plants are available during dry season. From September to November, floodwater starts. Fish and molluscs are collected year round. Average estimated value from flooded forest is 38,906 baht/household/year. Average income from fish alone is 9,284 Baht/household/year (Tham Mun Project, 1995).

Despite the close dependence upon natural wetland ecosystems, several factors combine to increase pressure upon the resources and decrease the benefits obtained by local communities. Threats to the Mekong wetlands include increased population and pressures; deforestation and degradation of watersheds; altered hydrological regimes, drainage, dredging, filling; development of unproductive acid sulphate soils; saline intrusion; reclamation schemes, irrigation, agriculture, aquaculture; hydroelectric schemes, flood control; groundwater abstraction; over-exploitation of wetland resources; water pollution; introduction of exotic species; and global climate change.

Large coastal mangrove areas such as in the Mekong Delta in Vietnam are cleared for shrimp ponds. Soils along the coastline erode more quickly. The productivity of the Tonle Sap Lake and River system is threatened by excessive sediment transport caused by upstream deforestation and gem mining, land conversion, improper irrigation development, and possibly over-fishing. A large portion of the flooded forests around Tonle Sap Lake has been cleared for agricultural land, firewood, and fish capture. Wetlands in Lao PDR face severe threats from fishing methods, introduced fish species, weed infestation (e.g. by *Mimosa pigra*), use of DDT and other persistent organochlorine pesticides, loss of wetland wildlife from over-hunting and habitat destruction, lack of property titles or rights of use, irrigation leading to salinization, sedimentation and erosion, and hydropower development. Thailand’s wetlands are being encroached upon and polluted by industry and human settlements. Infrastructure development and river flow regulation are another major causes of wetland degradation and loss as well as the invasion of non-native species and pollution.

Section 2: Potential Climate Change and Its Impacts on Mekong River Basin

2.1 Climate Change in Mekong River Basin: A Modeling Approach

The climate at any locations on earth are driven mainly by the net heat delivered from the sun and the net exchange of heat between that particular and surrounded locations. The circulation of air and water mass that bear heat in and out of that location control such heat exchange and therefore the heat, air mass and water mass budgets at any particular location may be, theoretically, calculated from a global circulation model (GCM) that couples land, atmosphere and ocean. An increase in the atmospheric greenhouse gases, such as carbon dioxide, will alter the global and regional heat budget, which will subsequently affect climate features, such as temperature and rainfall. GCM's can also project such changes.

At present there are over 15 GCM's available from various sources. However due to several technical and computational limitations, those global scale models still have the spatial resolutions in the range of hundreds of kilometer, which are far too course to be practical for impact assessment and policy planning at river basin and country/provincial scales in Southeast Asia. Those GCM's are, therefore, needed to be 'regionalized' to a finer resolution to allow local features to be reproduced.

At present there are generally three practical approaches to create regional scale climate projections with the resolution as fine as few ten kilometer or smaller from the GCM's.

- The first approach, the high resolution GCM, however this is still mostly in the experimental/development phase and therefore will not be discussed in this report;
- The second approach is to 'downscale' the GCM's outputs based on empirical information and some statistic techniques and/or atmosphere dynamic theories;
- The third approach is to develop a limited area regional climate model (RCM) that is based on atmosphere and ocean dynamics for that region and using the GCM's to drive the RCM at its boundary. This technique, also known as 'nesting', has been widely used in the operational prediction of weather and oceanographic features using numerical models.

Eventhough the downscaling approach has some advantages that it does not require a high performance computing facility and the approach is generally not very complicates to implement and therefore suitable as a tool to preliminary assess the change in climate at thew regional scale. However the approach does has several disadvantages.

- Firstly, it ignores the regional dynamics of the atmosphere and the ocean by assuming that these dynamics are the same as those in the global model.
- Secondly, the empirical relationships used in the downscaling may be valid only for the range of observed climate but may not be so for the future climate that may be changing beyond the range of present day information.
- Thirdly, the final resolution of the simulation depends in some degree to the availability of observed climate data. In the region where observation data is limited, the resolution can not be as high as in the data-riched regions.

This study adopts the third approach of using regional climate modeling approach (RCM) as it has an important advantage that it can produce very high resolution climate projections. It allows also for other features, such as land and sea surfaces surface land form and land cover be varied and climate be simulated under different combinations of atmospheric and land surface forcings. However the approach also has disadvantages in that it is subjected to the choice of boundary forcing by GCM to be used and the presently lack of 2-way interaction between RCM and GCM.

2.1.1 Future Socio-Economic Scenarios

As climate change will be driven mainly by greenhouse gasses, especially carbon dioxide (CO_2), emitted directly or indirectly from anthropogenic sources it is critical that social and economic of the world in the future must be evaluated. The plausible future need to be developed to give the picture of the future world, so the GHG emission from the world society in the future can be drawn upon. The Intergovernmental Panel on Climate Change (IPCC) had developed a Special Report on Emission Scenario (SRES) that has been widely referred to by scientific and other communities worldwide will be used in this report to estimate the CO_2 driven climate change in Southeast Asia.

These scenarios may be briefly summarized as:

- **SRES A1**: A future world of very rapid economic growth, low population growth, and rapid introduction of new and more efficient technology. Major underlying themes are economic and cultural convergence and capacity-building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil-intensive (**A1FI**), non-fossil energy sources (**A1T**), or a balance across all sources (**A1B**).

    - World economy grows at 3.3% over the period 1990–2080. The per capita GDP in 2080 amounts to $76,000 in the developed world and $42,000 in the developing world. The average income ratio between currently developed and developing countries was 13.8 in 1990 and this reduces to 1.8 in 2080. Thus it is an equitable world where current distinctions between poor and rich countries eventually dissolve.
    - Demographic transition to low mortality and fertility; the world sees an end to population growth. The total population for developing countries reaches 7,100 million in 2050 and then declines to 6,600 million in 2080, whereas the population in the developed world stabilizes at 1,250 million in 2050.
    - Environmental quality is achieved through active measures emphasizing "conservation" of nature changes towards active "management" – and marketing – of natural and environmental services.
    - Final energy intensity decreases at an average annual rate of 1.3%; transport systems evolve to high car ownership, sprawling sub-urbanization, and dense transport networks, nationally and internationally; large regional differences in future GHG emission levels.

- **SRES A2**: A very heterogeneous world. The underlying theme is that of strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development.

    - World economy grows at 2.3% over the period 1990–2080. The per capita GDP in 2080 amounts to $37,000 in the developed world and $7,300 in the developing world. The average income ratio between currently developed and developing countries was 13.8 in 1990 and this reduces to 5.1 in 2080. Thus it is a world where income disparities have been reduced by about two thirds of current levels.

- Rapid population growth continues, reaching a world total of 11 billion in 2050 and almost 14 billion in 2080. The total population of developing countries reaches 9.4 billion in 2050 and 11.7 billion in 2080, whereas the population in the developed world reaches 1.4 billion in 2050 and 1.6 billion in 2080. Social and political structures diversify, with some regions moving toward stronger welfare systems.
- Environmental concerns are relatively weak, although some attention is paid to bringing local pollution under control and maintaining local environmental amenities.
- The fuel mix in different regions is determined primarily by resource availability; technological change is rapid in some regions and slow in others; high energy and carbon intensity, and correspondingly high GHG emissions.

o **SRES B1**: A convergent world with rapid change in economic structures, “dematerialization,” and introduction of clean technologies. The emphasis is on global solutions to environmental and social sustainability, including concerted efforts for rapid technology development, dematerialization of the economy, and improving equity.

- World economy grows at 2.9% over the period 1990–2080. The per capita GDP in 2080 amounts to $55,000 in the developed world and $29,000 in the developing world. The average income ratio between currently developed and developing countries was 13.8 in 1990 and this reduces to 2.0 in 2080. Thus it is an equitable world where current distinctions between poor and rich countries eventually dissolve.
- Demographic transition to low mortality and fertility; the world sees an end to population growth. The total population for developing countries reaches 7,100 million in 2050 and than declines to 6,600 million in 2080, whereas the population in the developed world stabilizes at 1,250 million in 2050. High level of environmental and social consciousness combines with a globally coherent approach to sustainable development.
- Environmental consciousness and institutional effectiveness; high environmental quality is high; increasing resource efficiency; reduction of material wastage, maximizing reuse and recycling.
- Smooth transition to alternative energy systems as conventional oil resources decline; high levels of material and energy saving as well as reductions in pollution; transboundary air pollution is basically eliminated in the long term; low GHG emissions.

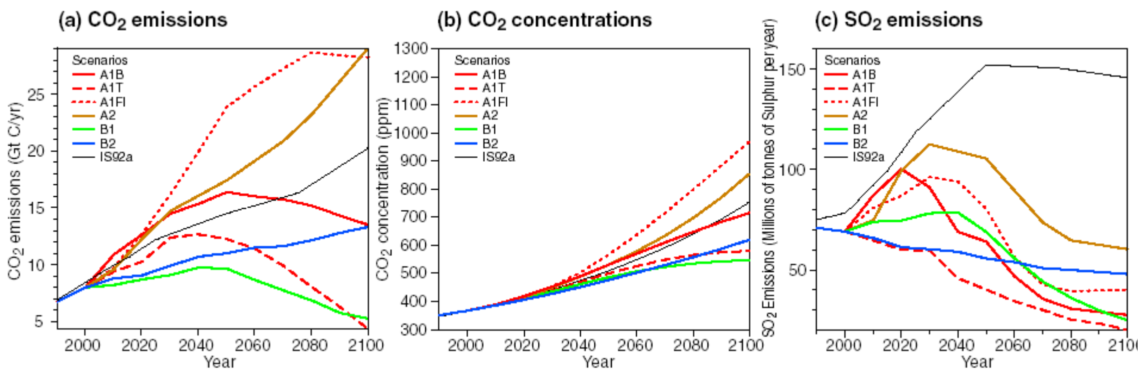
o **SRES B2**: A world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is again a heterogeneous world with less rapid and more diverse technological change, but a strong emphasis on community initiative and social innovation to find local, rather than global solutions.

- World economy grows at 2.7% over the period 1990–2080. The per capita GDP in 2080 amounts to $47,000 in the developed world and $18,000 in the developing world. The average income ratio between currently developed and developing countries was 13.8 in 1990 and this reduces to 2.6 in 2080. Thus it is a world where income disparities have been reduced by over four- fifths of current levels.
- Population growth continues, reaching a world total of 9.3 billion in 2050 and almost 10.1 billion in 2080. The total population for developing countries reaches 7.9 billion in 2050 and 8.7 billion in 2080, whereas the population in the developed world reaches 1.2 billion in 2050 and then declines to 1.1 billion in 2080. Social and political structures diversify, with some regions moving toward

stronger welfare systems; increased concern for environmental and social sustainability.

- Environmental protection is an international priority; improved management of some transboundary environmental problems.
- Energy systems differ from region to region, depending on the availability of natural resources; energy intensity of GDP declines by about 1% per year; technical change across regions is uneven; low level of car dependence and less urban sprawl; transition away from fossil resources; development of less carbon-intensive technology in some regions.

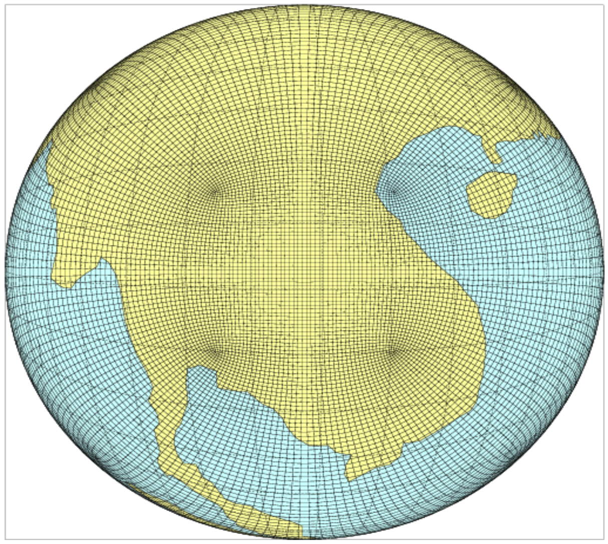
The level of GHG in the global atmosphere under these SRES Scenarios are shown as follows:



2.1.2 Climate Model

Climate change under this study is based on the true regional climate modelling as the downscaling technique has been proven to be unable to give accurate result for the region. The Conformal Cubic Atmospheric Model (CCAM) was used. CCAM is a regional climate model developed specifically for Australasian region by the CSIRO Division of Atmospheric Research in Australia. The model uses the principle of stretched coordinate of a global model instead of uniform latitude-longitude gridding system and runs for 18 vertical levels including the stratosphere. CCAM had also been evaluated in several international model intercomparison exercises to be among the best climate model for Asian region. In this preliminary study of the impact of climate change on the Mekong River Basin, two sets of modelling were carried out. The First Generation Run comprises of a preliminary run at 80-km and run only for one year for $1xCO_2$ and one year for $2xCO_2$ in the atmosphere. The model; was calibrated only to a limited number of observing stations. The Second Generation Run comprises of more calibration and verification. The Runs also cover the period of 10 years each for 1x and 2x atmosphric CO_2 and thus allowing the interannual climate variabilities, such those due to ENSO phenomenon, to be seen. All the output resolution was interpolated to 0.1 degree (about 10 km).

Stretched coordinate system for CCAM modeling of the Mekong basin



2.2 Climate Change in Mekong River Basin: When & How?

Climate scenarios for the whole Mekong Basin were derived for present atmospheric CO_2 level at about 350 ppm and at 700 ppm. Based on IPCC SRES, the year that atmosphric CO_2 will reach 700 ppm would be:

SRES Scenario	Doubled CO_2 in Year
A1FI	2070
A2	2080
A1B	2100
B2	2120
B1	Will not reach

For each atmospheric CO_2 level, CCAM was run for a continuous period of 10 years to allow interannual varibility such as those caused by ENSO to be reproduced in the model output. Monthly climatic patterns, namely rainfall, daily maximum temperature and daily minimum temperature were derived for the entire Mekong Basin as well as for the five major landforms:

- The Lancang Basin
- Northern Highlands
- Korat-Sakon Plateau
- Eastern Highlands
- Lowlands which includes the Southern Uplands part of Cambodia.

2.2.1 Results from the Low Resolution First Generation CCAM Runs

The main purpose of these Runs is to demonstrate hom climate modelling results can be used and interpreted in the context of the impact of climate change and water related resources in a large river basin. It is not intended to be the real assessment and should not be referred to as the real climate scenario for the region, but because of the eases to excecute the model and output simplicity, it is a good material for the beginners to understand and learn about the climate change impact asessment on a step-by-step approach.

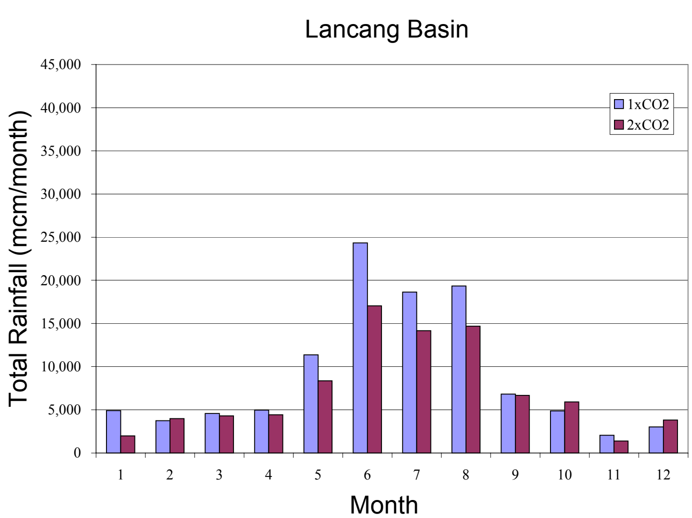
2.2.1.1 Change in Rainfall and Season Pattern (First Generation Runs)

The outputs shown in this part are the result of the preliminary CCAM run for an average year for present and doubled CO_2 levels.

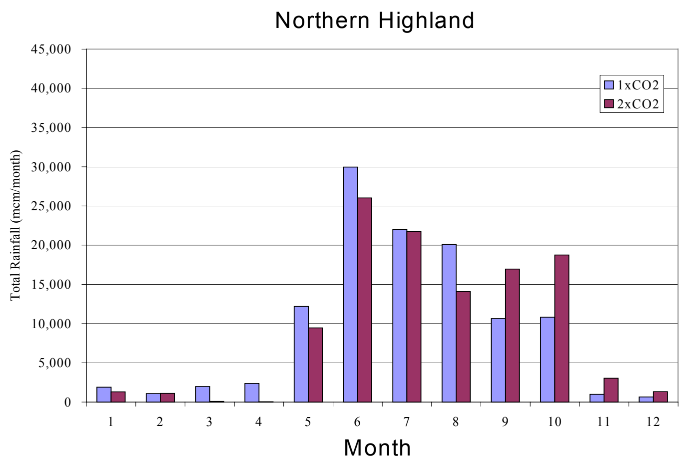
The result from the simple First Generation CCAM climate model shows that there will be significant change in the pattern of the rainfall all over the region. Generally over the Southeast Asia under the doubled atmospheric CO2, the season will shift and change pattern. The Mekong region will experience the dry season which will be dryer and longer. Dry season months (December-April) will be the same or slightly dryer except for the southeastern part toward the mouth of the Mekong and South China Sea coast of south Viet Nam will be dryer. The rainy season will begin in June instead of May and last until November with a short break in August. The Thai-Malay Peninsula will be more arid in June-August but the sea area, especially the Gulf of Thailand and Andaman Sea will receive more rain.

Change in rainfall pattern in each of the landform division would be as following summary:

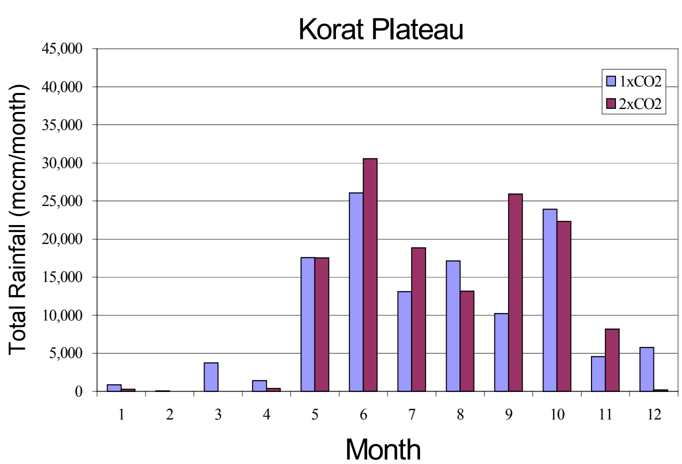
Lancang Basin. It is likely that this region may experience less rainfall throughout the year, but the season pattern may continue to be more or less the same as of today. Rain rate during the dry season months (September-April) will be generally the same but over the wet season (May-August) rainfall will be significantly lower. This part will be the only part of the Mekong Basin where the annual rainfall will be significantly reduced; from 109 billion cubic-meter (bcm) per year to 87 bcm per year, or about 20% reduction.



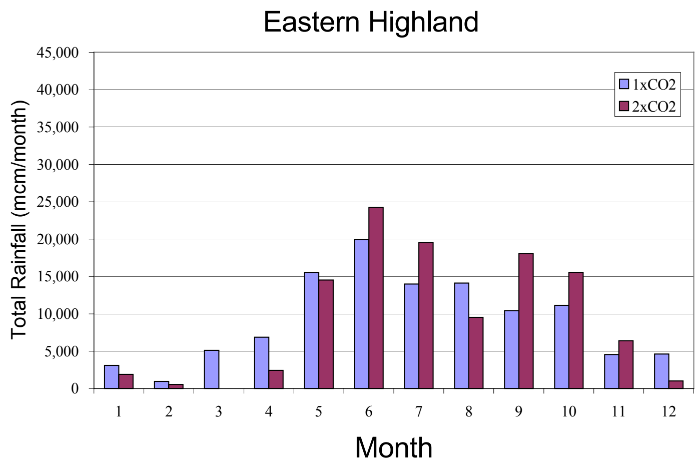
Northern Highland. This area may experience the shift in the season pattern. There will be slightly less rain during the first 2 month of the wet season (May-June), but toward the last 2 month of the season (September-October) rainfall will be significantly increased. There is a tendency that rainfall during the mid-rainy season may be reduced. The annual rainfall for this landform, however, will remain to be the same at about 114 bcm per year.



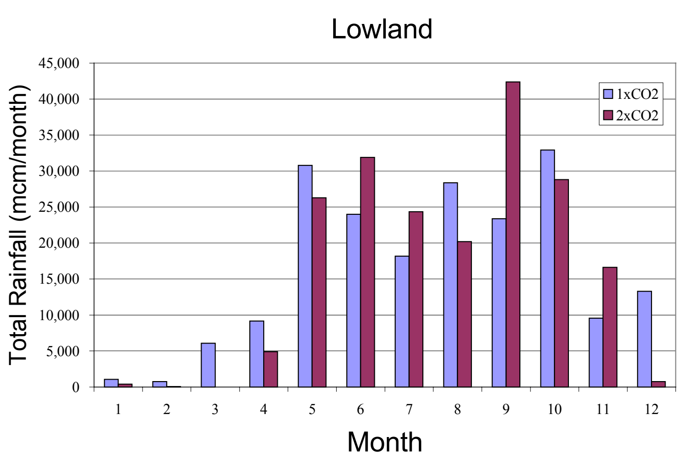
Korat Plateau. This area may also experience significant shift in season. Rainfall during the early months of the wet season will be increased especially July. The dry spell between the early season rain peak and late season rain peak will be reduced from 3 months (July-September) to 2 months (July-August). The spots that will be particularly more wet in June and July will be the southern provinces (Attapue, Champassak and Sekong) and central provinces (Borikhamxay) of Lao PDR. The late season rain peak will be longer and more rain, especially in September when the monthly rainfall will be increased from 15 bcm per month to 26 bcm per month, or more than 150% increase. The overall rainfall in Korat Plateau will be increased from 124 bcm per year to 137 bcm per year, or about 10% increase.



Eastern Highland. This area may experience a longer and dryer season but wetter rainy season. Generally the rainy season will be shorter by about 2 months as the season onset will be delayed from March to April, while the season offset will be earlier from December to November. The early and late season rain peaks will be more prominent as the rain rate during these peaks (May-July and September-October) will be about 20% and 60% higher, respectively, while the rain in August dry spell will be reduced by about 30%. The total rainfall in this Eastern Highland area will be slightly increased from 110 bcm per year to about 114 bcm per year, or by about 3%.



Lowland. Similar to the Eastern Highland, the dry season will be dryer and longer and the rainy season will be shorter and wetter. The wet season in this part of the Mekong Basin will be reduced by about 2 months with a clearer lag between peaks. The month of September will have particularly more rain with the monthly rainfall increased by about 80%. However, over the year the total rainfall in this landform will remain to be the same at about 197 bcm per year.



2.2.2 Results from the Medium Resolution Second Generation CCAM Runs

Climate scenarios obtained from this modelling approach should be more realistic and accurate than those from the First Generation Runs. In addition these Second Generation Runs also give the scenario over a decade and hence year-to-year variability as well.

2.2.2.1 Change in Averaged Monthly Rainfall Over the Entire Mekong River Basin (Second Generation Runs)

The preliminary result from the climate model shows that there will be significant change in the pattern of the rainfall all over the region. Generally over the Southeast Asia under the doubled atmospheric CO_2, the rainy and dry seasons will be shifted and the pattern be changed. The Mekong region will experience the dry season which will be dryer and longer. Dry season months (December-April) will be the same or slightly dryer except for the southeastern part toward the mouth of the Mekong and South China Sea coast of south Viet Nam will be dryer. The rainy season will begin in June instead of May and last until November with a short break in August. The Thai-Malay Peninsula will be more arid in June-August but the sea area, especially the Gulf of Thailand and Andaman Sea will receive more rain.

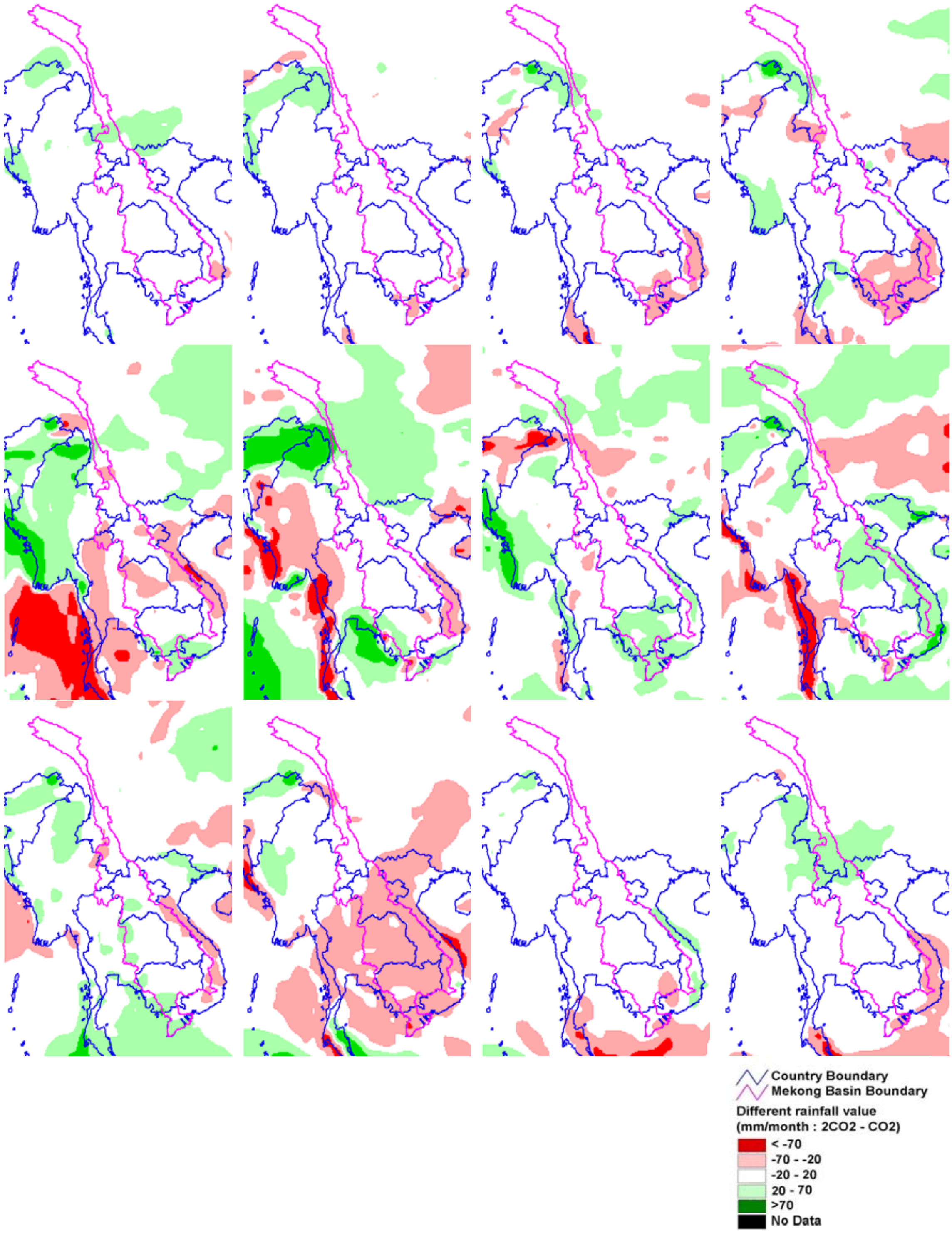


Figure 1: Different in the 10-year averaged monthly rainfall (mm/month) when atmospheric CO_2 has increased from 350 to 700 ppm.

2.2.2.2 Change in Rainfall and Seasonality in Each Landform (Second Generation Runs)

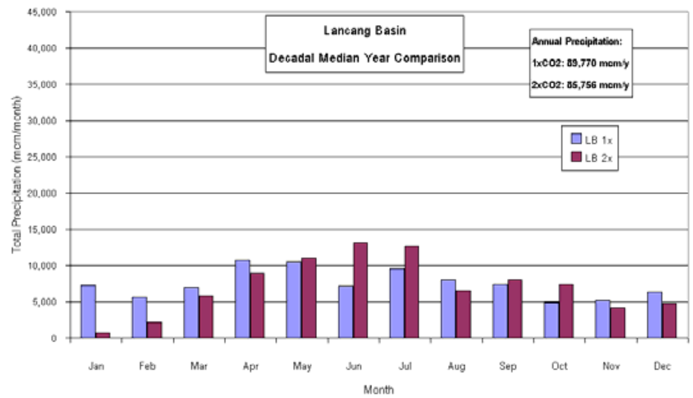
Comparison of rainfall pattern between present and future atmospheric CO_2 for each landform will be done between the two years that belong to the same water regime instead of using the decadal averages to ensure that temporal variability especially rainfall onset and offset are not averaged out during the process. In each decade, 3 years will be selected for comparison, namely the median year for that decade, the wettest year of that decade, and the driest year of the decade. These three years will represent the ‘normal’, wet and dry years respectively for each decade,

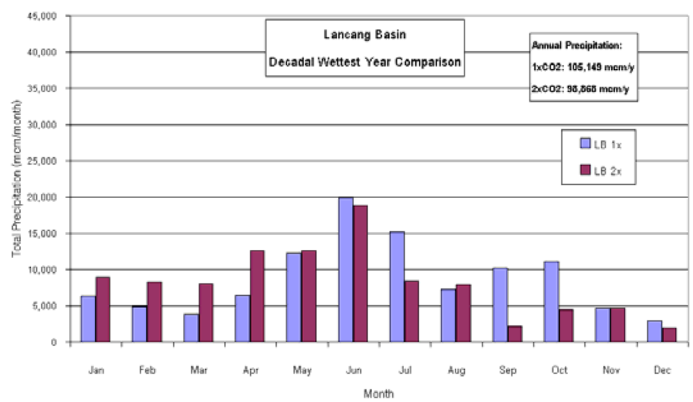
Lancang Basin.

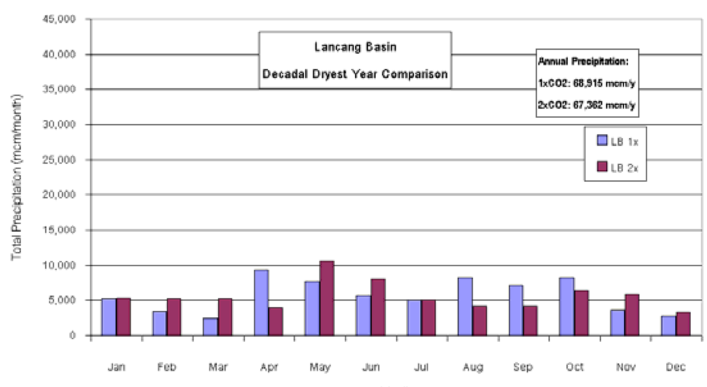
Median years—this landform may experience less annual rainfall by about 5% but there will be especially less rainfall during January and February, while substantially more rain in June and July.

Wet years—with the doubling of the atmospheric CO_2, there will be substantially more rain in January-April but will be less rain during the last part of the rainy season (July-October). The wettest years in the future may not be as wet as what it used to be with the reduction in annual rainfall by about 6%.

Dry years—generally both the onset and offset of rainy season will be delayed by about one month. However there tends to be slightly more rain during the early rainy season but this may not be so significant.





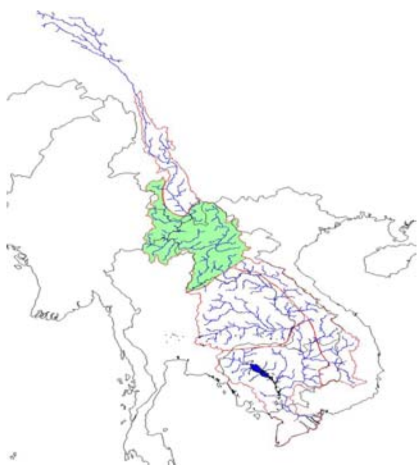


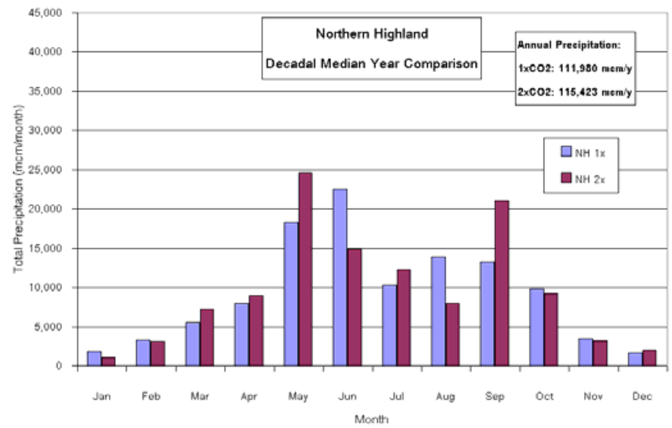
Northern Highland.

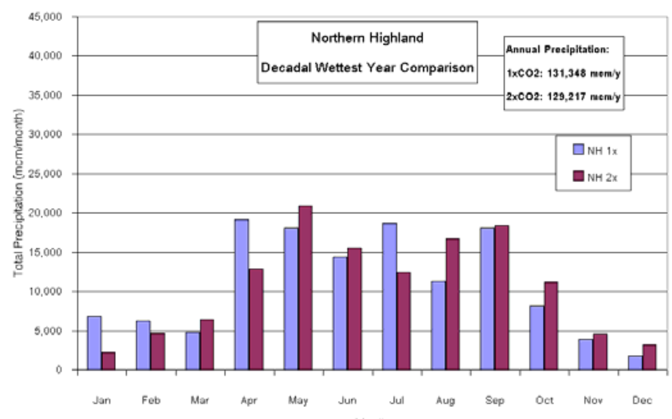
Median years—the onset of rainy season will be earlier by about one month from Jane to May. The second rain peak in September will be larger and thus increases the annual rainfall for the 'normal' years by about 5%..

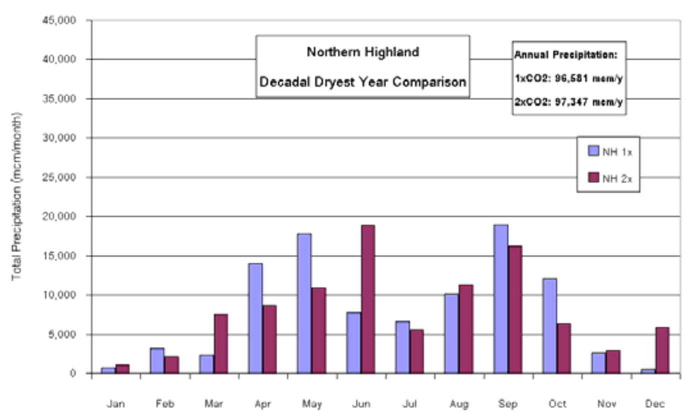
Wet years—there will be no significant change in the overall rainfall and only some slight changes in the intramural variability.

Dry years—the early rain peak will be significantly broaden to span over March to June, with the wettest month in June. The offset of rainy season will occur a little earlier than present. In overall the dry season will be generally longer and rainy season will be shorter but more intense but there will be no significant change in the annual rainfall.







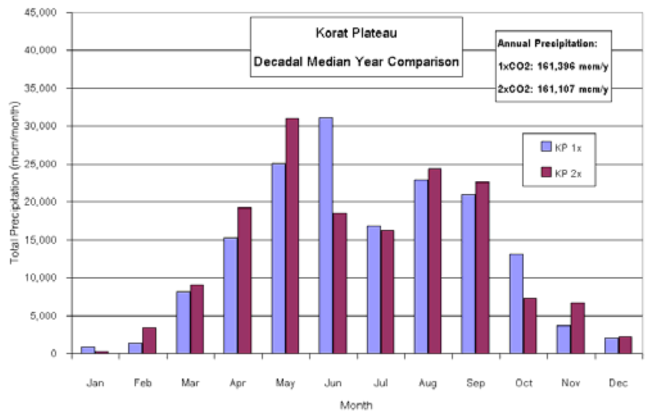


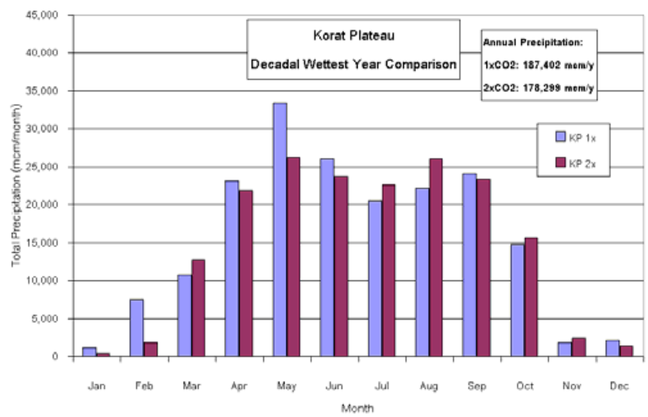
Korat Plateau.

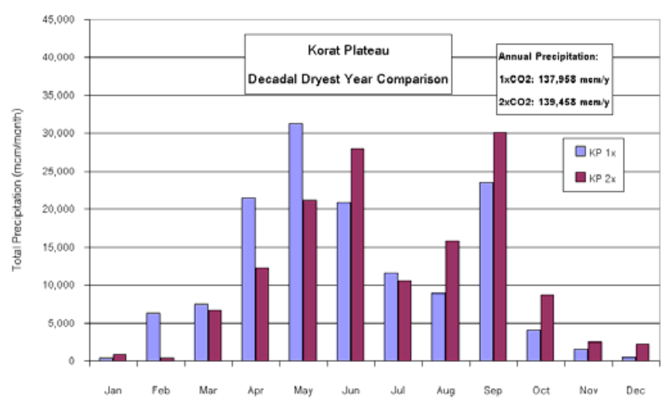
Median years—the onset of rainy season will be clearly be early by about one month while the will e only slight change in the timing of the offset. This causes the intra-season rain lag period increased also from one month to about two months.

Wet years—only observable changes would be some reduction in rainfall in the months of February and May.

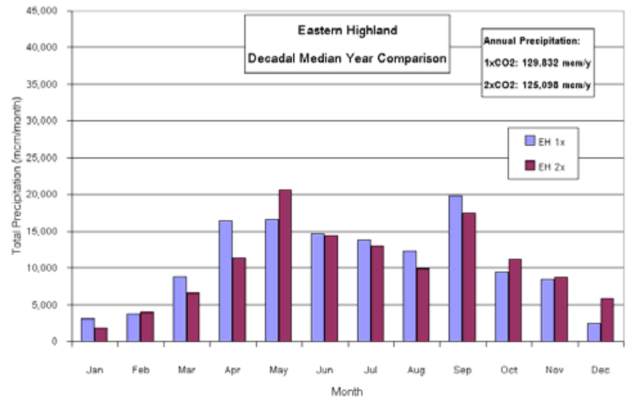
Dry years—the onset of rainy season will be delayed by about one month with the new early rain peak occurs in June. The second rain peak will be more intense. In overall, the rainy season will be shorten by about one month with no changes in annual rainfall.

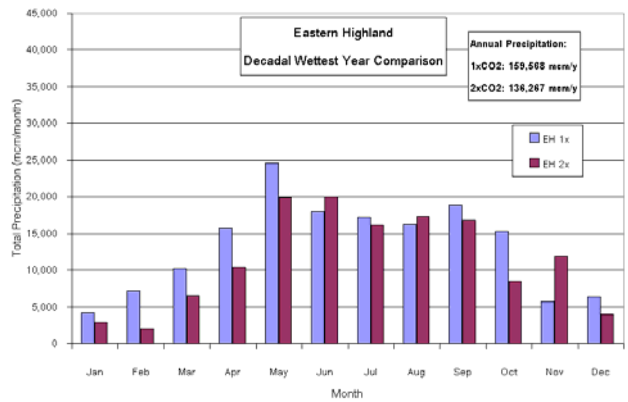


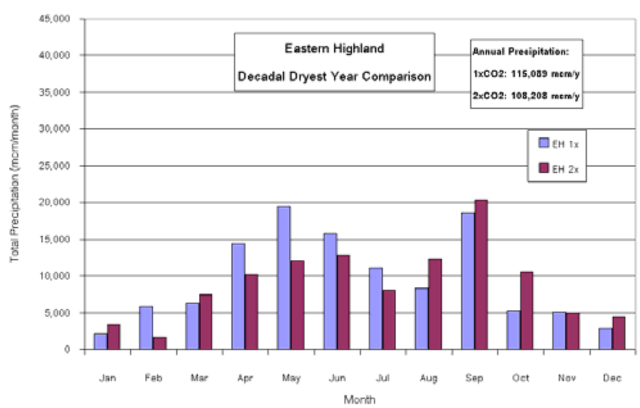




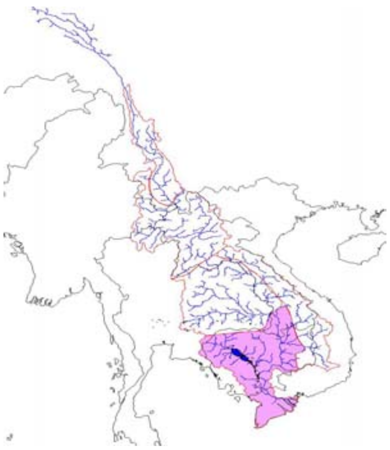
Eastern Highland.
Median years—there will be only slight change in rainfall by having less rain in the months of March and April while the May rain peak will be slightly more intense. .
Wet years—will not be as wet as they used to be with a reduction in annual rainfall by about 15%. This is due mainly to a lower rain rate in most of the dry season months. Rainy season will also be shorten by up to two months due to late onset and early offset of the season.
Dry years—will also be drier by about 6% as a result of a less rainfall in the months of April to July but there will be a slight increases in rainfall during the second rain peak (August to October).

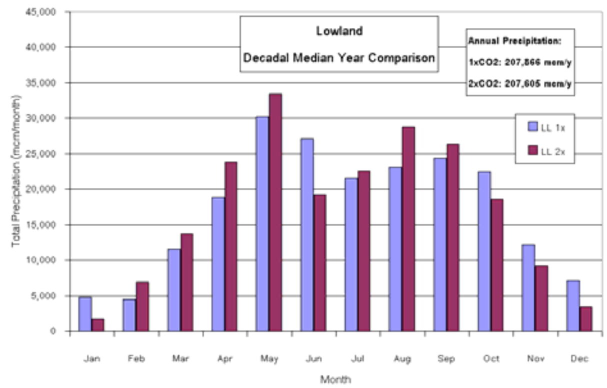


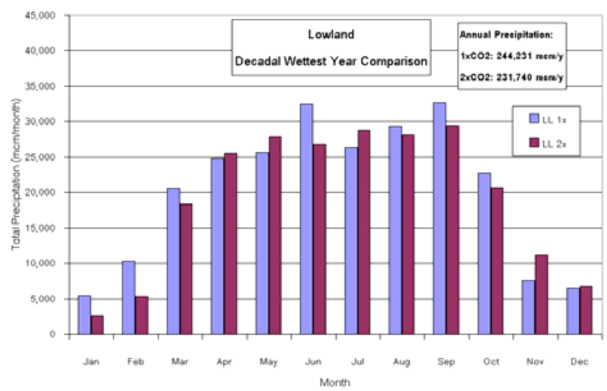


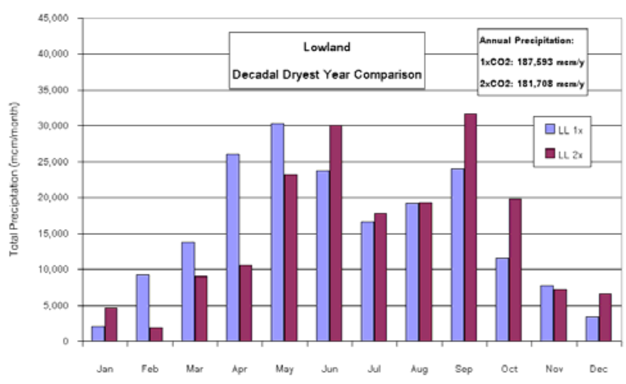


Lowland.
Median years—will be mostly the same as present with some what more intense rain during both rain peaks and less rainfall in the month of June.
Wet years—also will not be much affected by CO_2 induced climate change. Generally annual rainfall will be reduced by about 5% as a result of a less rainfall in several month of the year.
Dry years—seasonality will be strongly affected by atmospheric CO_2 increase even though less effects on the total annual rainfall. The rainy season will be substantially shorten by about one month with more intense rain toward the end of the season (September and October). Dry season, especially from February to April will also be much drier than present.









2.2.2.3 Temperature and Other Climatic Variables (Second Generation Runs)

The daily maximum temperature, or an indication of daytime temperature, will be higher by 1-3 degree Celcius especially in January to May. The changing pattern will be very similar to the changing rainfall as the daytime temperature change will be owing mainly to cloud cover. The Eastern Highland part of the Mekong Basin will be most affected. From June to August the temperature change will be smaller and less systematic. In July, most of the Lower Mekong will be cooler but in August, when intra-seasonal rain lag occurs, the daytime temperature will be lower. Toward the last four months of the year the basin will be generally cooler by 1-3 degree Celcius especially in the Northern and Eastern Highlands.

The change in the daily minimum temperature, or the nighttime temperature, will roughly follow the daytime temperature change but in a lesser magnitude as it reflects the total heat received during the day. In overall, the nights will be warmer for most part of the Mekong and for most months except in September and December when the central parts of the Basin will slightly cooler by about 1-2 degree Celcius.

The prevailing wind pattern will be changed as the timing for the migration of the Inter Tropical Convergence Zone (ITCZ) will be differed. The average wind speed over land will be only slightly changed while in the sea areas the wind speed will be higher for most of the year.

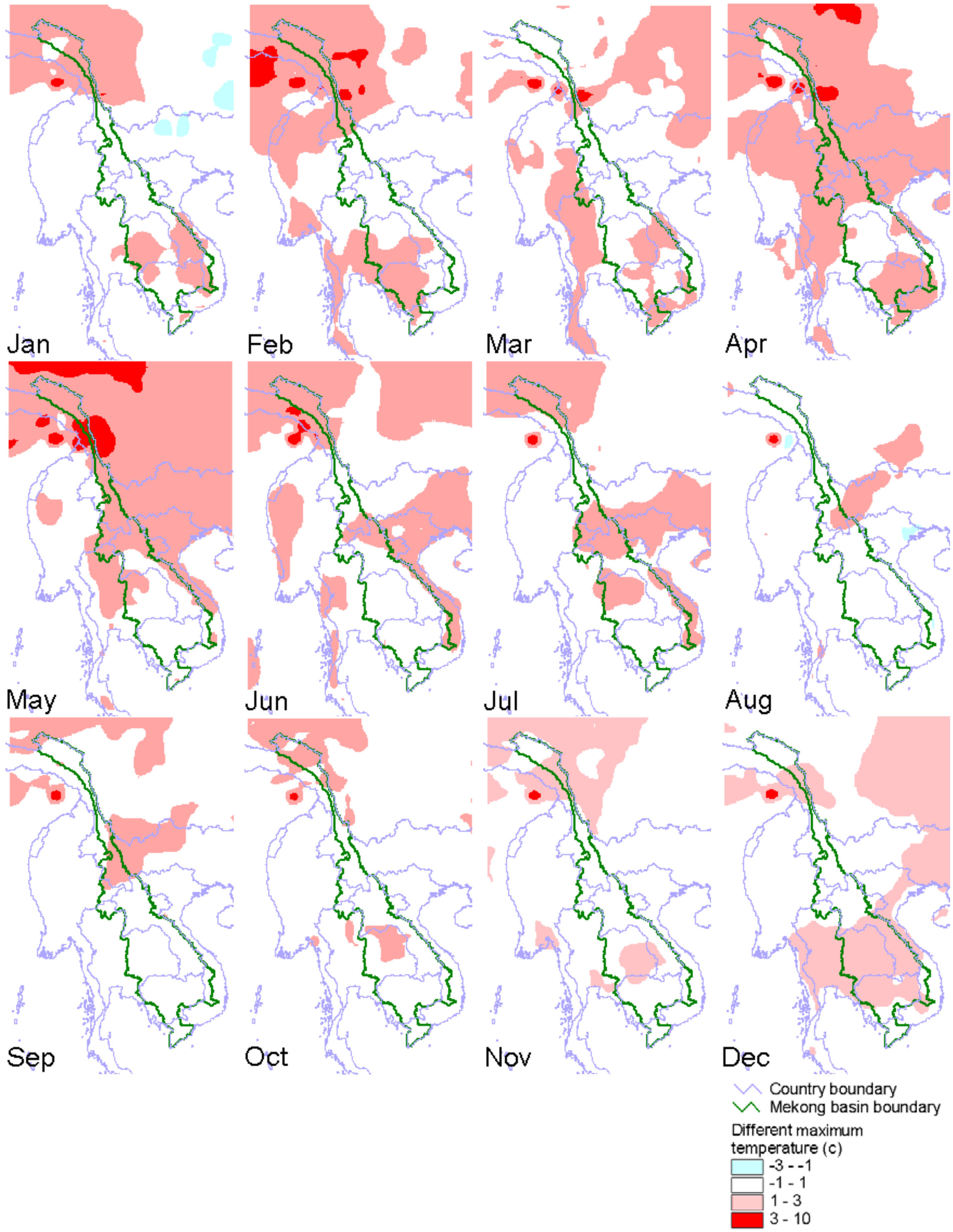


Figure 2: Different in average monthly maximum temperature, comparison of the average monthly maximum temperature at 1xCO_2 at present time and 2xCO_2 levels in the future.

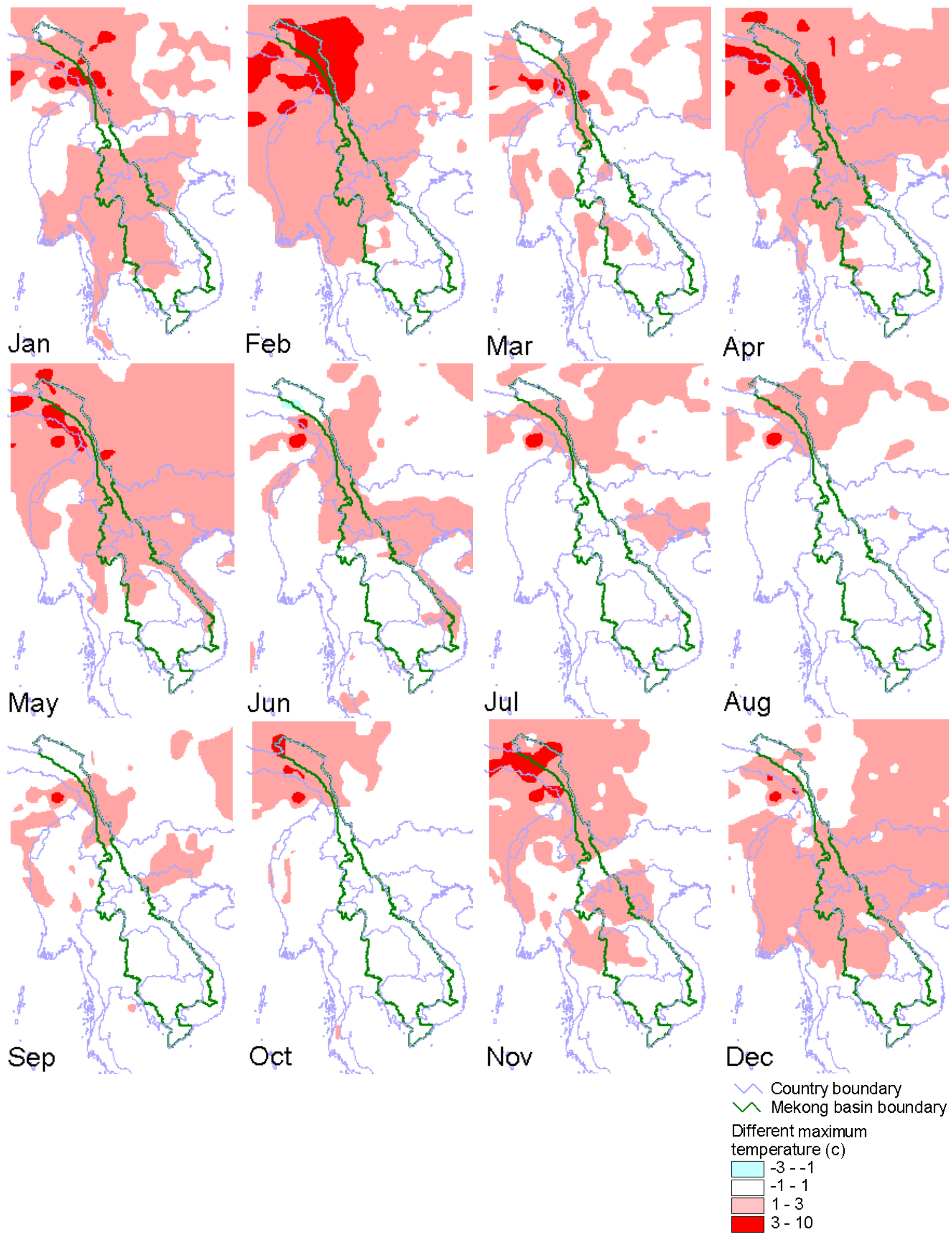


Figure 3: Different in average monthly minimum temperature, comparison of the average monthly minimum temperature at $1xCO_2$ at present time and $2xCO_2$ levels in the future.

2.3 Potential Impact of Climate Change in Mekong River Basin: What may Happen in the Region?

Although at the global scale over the last century, climate change had been observed, at the scale of the Mekong Basin, there has been no clear indication that any local and regional climate and hydrology might had significantly been changed. For example, the discharge at Chiang San, which would represent the integrated runoff over the Lancang-Yunnan landform division, has not demonstrated any trends of annual flow even though according to the model, rainfall this landform division would be sensitively reduced as a result of atmospheric CO_2 increase.

In the past and present the climate variability, such as ENSO, and local factors, such as land uses and water management, have dominated the water and wetland resource in the Mekong than the CO_2 driven climate change. Thus, the risen in global atmospheric CO_2 over the last century by about 100 ppm from about 270 ppm to the present value might not be significant enough for the gradual climatic and hydrological trends to be differentiated from short term 'noises'. However, over the next century, most SRES scenarios predict that the atmospheric CO_2 may increase by more than 300 ppm, in other words, double of today.

As an example on how the outputs from regional climate model can be used to assess the impact of climate change on various development sectors, the outputs from the First Generation Runs will be emphasized in this section. Using of the outputs from the Second Generation Runs, although mathematically more accurate and reliable, they are far more complicate and need a much longer time and resource to analyze properly. Analyzing those complicated modelling oputputs in some simple ways may mislead the assessment results and therefore be avioded in this report.

Some examples of impacts of climate change on selected water related sectors in the Mekong Basin can be summarized by the 4 major sectors as follows.

2.3.1 Water Supply

The upper Mekong especially in Yunnan Province of China will be subjected to a significant reduction in the annual supply of water. Fortunately, the rainfall in the dry season will not be much reduced, therefore communities that depends on direct rainfall may not feel much different in terms of water availability during the dry season. However, the irrigation system that will supply water to the irrigation-based communities may be suffered from water shortage, as the peak rainfall during the rainy season will be reduced by about 20%.

As the runoff in the upper Mekong will be reduced, so does the erosion along the mountain slopes. This would make the water quality in term of suspended solids in the future better than at present.

The Korat Plateau and the Southern Lowland will generally experience a shorter rainy season and longer dry season by about 2 months. However as the total rainfall over a year will be the same or slightly higher, the overall impact on water supply may not be so great providing that the community has sufficient storage of water to cover the longer dry season period.

This may also lead to the implication that the water quality in the region may get affected as there may be less water supply to flush out the pollution during the longer and dryer dry season.

Water demand would increase steadily, while climate change is expected to lead to a decrease in water availability, especially in longer dry season. Response measures to address climate change, e.g. dam construction, could have implications for wetlands and face with debates and obstruction. The construction of dams will put additional stress on wetland ecosystems by increasing habitat fragmentation. A future pressure to increase water storage capacity will increase.

The Northern and Eastern Highland parts may be least suffered as the water supply from rainfall in terms of seasonally and overall amount in these parts will be more or less unchanged. Yet there will be slightly less rain in dry season and slightly more rain during the last few months of the rainy season but that should not much affect these largely non-irrigated areas.

2.3.2 Human Settlement and Urbanization

The most prominent potential threat to urbanization in the Mekong would be the possibility of more severe flood in the Korat Plateau and the Southern Lowland areas as there will be a significant increase in rainfall especially in September-October in these areas. Although these two areas are largely flat land with backwater lakes and swampland that serve as buffer storage of excess water from the main stream of the Mekong, by late rainy season these natural storage systems will already reach their capacity. The reverse flow from the mainstream together with the more local rainfall will make flood during the late rainy season unavoidable.

During the dry season, the Great Lake of Cambodia has a water surface area of 3,000 sq. km. and a mean depth of 1 m. The Lake absorbs a considerable portion of the flood run-off from the Mekong. In a normal year the lake begins to rise in June and absorbs 80 bcm of water over a period of 100-120 days. Of this water only 34 bcm comes from the drainage area of the lake, the rest (46 bcm) comes from the Mekong. During this period the water level rises by 9 m and the surface area expands to 10,000 sq. km. From October to May, with the recession of the flood in the Mekong, the flow is reversed and the lake drains away through delta channels.

Riverine floodplains and riparian flooded forests depend solely on rises and falls of the Mekong and its tributaries. If annual inundation occurs longer or shorter than normal period, these wetland ecosystems as well as their functions and services would be affected.

Some communities, such as those based on capture fisheries, however may gain benefit from the optimal increases of flood level and duration. The detailed impacts on each community types need to be studied at the community level.

The less erosion potential in the Yunnan Province due to less rain implies that the soil will be more stable and cost of land protection may be reduced.

2.3.3 Natural Wetlands

It is believed at this point that tree species in natural wetland in most parts of the Mekong Basin, such as flooded forest, riparian swamps, and lakes, will receive minimal impacts from climate change. These wetlands need to be flooded for at least few months per year and the as the output from CCAM climate model indicate that there will be sufficient water especially during the peak flow degree of change. Flooding duration maybe changed or shifted slightly but these may be small enough that the ecosystem can cope with.

Some of the natural wetland in Lancang part may be dried out as a result of less rainfall. Much of these wetlands is the highland non-riparian type and depends strongly on the local rain.

The mangrove and *Melaleuca* forests in the delta area of the Mekong may be affected by changing hydrology to some degree, for example, in term of ambient salinity of water. A key factor which helps maintain the stability of *Melaleuca* forests in Vietnam is freshwater supply. Water is stored and regulated within the forest and the forest is flooded 5-6 months a year with depths less than 1.5 m. Such conditions help prevent soil acidification and promote the growth of *Melaleuca leucadendron.* If the dry season is longer in this region by 2 months, some of the trees may not thrive.

Individual animal species would have different capacity to respond to changes in climate due to difference in competitive abilities, migration rates, response to disturbance, and in other ways. Many species might be able to migrate providing that continuous, relatively undisturbed, natural ecosystems are available. Changes in the timing of seasonal events during the yearly cycle would have strong negative impacts for many species, especially migratory ones. Various species of bird and fish that migrate through these areas and use the wetland as a seasonal habitat may find the wetland in these areas inhabitable or not providing shelter, foods, etc. that they may need for that period of their life cycle. Species with narrow tolerance to environmental variability would be most vulnerable to change and most threatened by climate change.

2.3.4 Agriculture

Crop production, especially the rainfed rice cultivation, which is the main source of food in the region, will be strongly affected by hydrological change caused by atmospheric CO_2 elevation. The season shift and the change in precipitation pattern may have strong impact on the crop yield and crop cycle as the radiation (daylight), water level, distribtion of rainfall over time may change in the future. The generally shorter and more intense rainy season implies that the varieties of rice and other crops currently grown in each area may not be suitable in the future. Irrigated farmlands in most part, except in Yunnan part of the Mekong, may be less vulnerable as reservoirs may remain to store the same amount of water.

Some of the very low land may have to be abandoned as the flood level and duration may be too long for any crops to be survived or productive. These areas will need to be identified from the inundation maps to be generated for the region in the future.

Much of the study on the impact of climate change on rice had emphasized on the effects from UV, atmospheric CO_2 and temperature. The result could vary from place to place as shown for example Matthews et al. (1994) and Horie et al (2000). The region, however, need more studies on the impacts of climate change through the changes in seasonal timing and magnitude of rain especially on rain-fed rice paddy.

Section 3: Preparedness for adaptation[2]

3.1 Introduction: Adaptation to Climate Change in the Context of Sustainable Development and Equity

Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change.

Estimates of likely future adaptations are an essential ingredient in *impact and vulnerability assessments*. The extent to which ecosystems, food supplies, and sustainable development are vulnerable or "in danger" depends both on exposure to changes in climate and on the ability of the impacted system to adapt. In addition, adaptation is an important policy *response* option, along with mitigation. There is a need for the development and assessment of planned adaptation initiatives to help manage the risks of climate change.

Adaptations vary according to the system in which they occur, who undertakes them, the climatic stimuli that prompts them, and their timing, functions, forms, and effects. In unmanaged natural systems, adaptation is autonomous and reactive; it is the process by which species and ecosystems respond to changed conditions. This chapter focuses on adaptations consciously undertaken by humans, including those in economic sectors, managed ecosystems, resource use systems, settlements, communities, and regions. In human systems, adaptation is undertaken by private decision makers and by public agencies or governments.

Adaptation depends greatly on the *adaptive capacity* or adaptability of an affected system, region, or community to cope with the impacts and risks of climate change. The adaptive capacity of communities is determined by their socioeconomic characteristics. Enhancement of adaptive capacity represents a practical means of coping with changes and uncertainties in climate, including variability and extremes. In this way, enhancement of adaptive capacity reduces vulnerabilities and promotes sustainable development.

Adaptation to climate change has the potential to substantially reduce many of the adverse impacts of climate change and enhance beneficial impacts—though neither without cost nor without leaving residual damage.

The key features of climate change for vulnerability and adaptation are those related to variability and extremes, not simply changed average conditions. Most sectors and regions and communities are reasonably adaptable to changes in average conditions, particularly if they are gradual. However, these communities are more vulnerable and less adaptable to changes in the frequency and/or magnitude of conditions other than average, especially extremes.

Sectors and regions will tend to adapt autonomously to changes in climate conditions. Human systems have evolved a wide range of strategies to cope with climatic risks; these strategies have potential applications to climate change vulnerabilities. However, losses from climatic variations and extremes are substantial and, in some sectors, increasing. These losses indicate that autonomous adaptation has not been sufficient to offset damages associated with temporal variations in climatic conditions. The ecological, social, and economic costs of relying on reactive, autonomous adaptation to the cumulative effects of climate change are substantial.

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2 Many parts of this section are excerpt, primarily, from IPCC Third Assessment Report and Ramsar COP8 Document on Climate Change and Wetlands.

Planned anticipatory adaptation has the potential to reduce vulnerability and realize opportunities associated with climate change, regardless of autonomous adaptation. Implementation of adaptation policies, programs, and measures usually will have immediate benefits, as well as future benefits. Adaptation measures are likely to be implemented only if they are consistent with or integrated with decisions or programs that address nonclimatic stresses. The costs of adaptation often are marginal to other management or development costs.

The capacity to adapt varies considerably among regions, countries, and socioeconomic groups and will vary over time. The most vulnerable regions and communities are those that are highly exposed to hazardous climate change effects and have limited adaptive capacity. Countries with limited economic resources, low levels of technology, poor information and skills, poor infrastructure, unstable or weak institutions, and inequitable empowerment and access to resources have little capacity to adapt and are highly vulnerable.

Enhancement of adaptive capacity is a necessary condition for reducing vulnerability, particularly for the most vulnerable regions, nations, and socioeconomic groups. Activities required for the enhancement of adaptive capacity are essentially equivalent to those promoting sustainable development. Climate adaptation and equity goals can be jointly pursued by initiatives that promote the welfare of the poorest members of society—for example, by improving food security, facilitating access to safe water and health care, and providing shelter and access to other resources. Development decisions, activities, and programs play important roles in modifying the adaptive capacity of communities and regions, yet they tend not to take into account risks associated with climate variability and change. Inclusion of climatic risks in the design and implementation of development initiatives is necessary to reduce vulnerability and enhance sustainability.

Current knowledge of adaptation and adaptive capacity is insufficient for reliable prediction of adaptations; it also is insufficient for rigorous evaluation of planned adaptation options, measures, and policies of governments. Climate change vulnerability studies now usually consider adaptation, but they rarely go beyond identifying adaptation options that might be possible; there is little research on the dynamics of adaptation in human systems, the processes of adaptation decision-making, conditions that stimulate or constrain adaptation, and the role of non-climatic factors. There are serious limitations in existing evaluations of adaptation options: Economic benefits and costs are important criteria but are not sufficient to adequately determine the appropriateness of adaptation measures; there also has been little research to date on the roles and responsibilities in adaptation of individuals, communities, corporations, private and public institutions, governments, and international organizations. Given the scope and variety of specific adaptation options across sectors, individuals, communities, and locations, as well as the variety of participants—private and public—involved in most adaptation initiatives, it is probably infeasible to systematically evaluate lists of particular adaptation measures; improving and applying knowledge on the constraints and opportunities for enhancing adaptive capacity is necessary to reduce vulnerabilities associated with climate change.

Six reasons to adapt to climate change now (Burton, 1996).

1) Climate change cannot be totally avoided.

2) Anticipatory and precautionary adaptation is more effective and less costly than forced, last-minute, emergency adaptation or retrofitting.

3) Climate change may be more rapid and more pronounced than current estimates suggest. Unexpected events are possible.

4) Immediate benefits can be gained from better adaptation to climate variability and extreme atmospheric events.

5) Immediate benefits also can be gained by removing maladaptive policies and practices.

6) Climate change brings opportunities as well as threats. Future benefits can result from climate change.

Adaptation here is taken to be a human intervention to address the effects of climate change, and does not include the autonomous response of the ecosystems themselves, for example an increased net primary productivity in many species due to the increased levels of atmospheric concentrations of carbon dioxide (IPCC 2001b).

Adaptation options and their implementation are thus strongly dependent on institutional capacity in the region or country. Specifically, institutional capacity includes both financial and human resources as well as the political will to address the adaptation options for climate change. Such political will can often be related to the national current and future socio-economic development and the current extent of the country's exposure to climate change. The potential for adaptation is more limited for developing countries, which are projected to be the most adversely affected.

Adaptation appears to be easier if the climate changes are modest and/or gradual rather than large and/or abrupt. Many of the adaptation options can not only address climate change impacts but could also provide "win-win" option for other problems, such as wetland degradation (IPCC 2001b). Adaptation options are often limited by our state of scientific knowledge. However, implementing these options, especially the "win-win" options, is often a function of political and governance decisions rather than of the state of scientific knowledge (Finlayson 1999).

Adaptation options should be considered within overall frameworks for sustainable development and should not conflict with the wise use of wetlands. However, given the inertia in some wetland species and functions, the development of adaptation options may not result in rapid responses (Gitay et al 2001). In addition, there is also likely to be institutional inertia. For example, implementation of management plans may be on a ten-year cycle, and that could affect the planning and implementation of adaptation options.

Monitoring of adaptation options should be considered to be an essential feature so that the overall adaptive framework, which should be responsive to the changes being observed either as a result of the adaptation measures or some other factors, can be modified as needed. In this sense the framework for adaptation and mitigation options illustrates the extent of connections that exist between wetlands, their goods and services, and various pressures, including that of climate change.

3.2 Adaptation to Climate Change in the Water Sector

A commonly prescribed adaptation to climate change in the water sector is to enhance characteristics that offer flexibility hence enhancing resilience. Flexibility issues are particularly important with regard to the development of water resources for industry or agriculture. Major projects such as dams actually may limit flexibility if they lose effectiveness as regional hydrological water balances undergo major changes. With likely changes in climate variability, dams and sea defenses built to withstand a 100-year extreme event may not be adequate thus leading to a risk of major catastrophe. If hydrological patterns change markedly and irrigated agriculture is required to relocate in response, prior investments may be lost as existing infrastructures become obsolete, and additional investments will be needed. This necessitates critical scrutiny of a range of available choices that incorporate economic and environmental concerns. The potential for adaptation should not lead to complacency (Rosenzweig and Hillel, 1995). Some adaptive measures may have detrimental impacts of their own.

Examples of adaptation options for selected sectors

Sector/System	Adaptation Options
Water	o Increase water-use efficiency with “demand-side” management (e.g., pricing incentives, regulations, technology standards). o Increase water supply, or reliability of water supply, with “supply-side” management (e.g., construct new water storage and diversion infrastructure). o Change institutional and legal framework to facilitate transfer of water among users (e.g., establish water markets). o Reduce nutrient loadings of rivers and protect/augment streamside vegetation to offset eutrophying effects of higher water temperatures. o Reform flood management plans to reduce downstream flood peaks; reduce paved surfaces and use vegetation to reduce storm runoff and increase water infiltration. o Re-evaluate design criteria of dams, levees and other infrastructure for flood protection.

3.2.1 Water Management Options

Water management is based on minimization of risk and adaptation to changing circumstances (usually taking the form of altered demands). A wide range of adaptation techniques has been developed and applied in the water sector over decades. One widely used classification distinguishes between increasing capacity (e.g., building reservoirs or structural flood defenses), changing operating rules for existing structures and systems, managing demand, and changing institutional practices. The first two often are termed "supply-side" strategies, whereas the latter two are "demand-side." Over the past few years, there has been a considerable increase in interest in demand-side techniques. International agencies such as the World Bank (World Bank, 1993) and initiatives such as the Global Water Partnership are promoting new ways of managing and pricing water resources to manage resources more effectively (Kindler, 2000).

This work is going on largely independently of climate change, but changes in water management practices will have a very significant impact on how climate change affects the water sector. Water managers in some countries are beginning to consider climate change explicitly, although the methodologies for doing so are not yet well defined and vary between and within countries depending on the institutional arrangements for long-term water resources planning.

Clearly, however, the ability of water management agencies to alter management practices in general or to incorporate climate change varies considerably between countries.

The table below summarizes some supply- and demand-side adaptive options, by water-use sector. Each option has a set of economic, environmental, and political advantages and disadvantages.

Supply-side and demand-side adaptive options: some examples.

Supply-Side		**Demand-Side**	
Option	***Comments***	***Option***	***Comments***
Municipal water supply			
– Increase reservoir capacity – Extract more from rivers or groundwater – Alter system operating rules – Inter-basin transfer – Desalination – Seasonal forecasting	Expensive; potential environmantal impact – Potential environmental impact – Possibly limited opportunity – Expensive; potential environmental impact – Expensive (high energy use) – Increasingly feasible	– Incentives to use less (e.g., through pricing) – Legally enforceable water use standards (e.g., for appliances) – Increase use of grey water – Reduce leakage – Development of non-water-based sanitation systems	Possibly limited opportunity; needs institutional framework – Potential political impact; usually cost-inefficient – Potentially expensive – Potentially expensive to reduce to very low levels, especially in old systems – Possibly too technically advanced for wide application
Irrigation			

– Increase irrigation source capacity	– Expensive; potential environmental impact	– Increase irrigation-use efficiency – Increase drought-toleration – Change crop patterns	– By technology or through increasing prices – Genetic engineering is controversial – Move to crops that need less or no irrigation
Industrial and power station cooling			
– Increase source capacity – Use of low-grade water	– Expensive – Increasingly used	– Increase water-use efficiency and water recycling	– Possibly expensive to upgrade
Hydropower generation			
– Increase reservoir capacity	– Expensive; potential environmental impact – May not be feasible	– Increase efficiency of turbines; encourage energy efficiency	– Possibly expensive to upgrade
Navigation			
– Build weirs and locks	– Expensive; potential environmental impact – Potential environmental impact	– Alter ship size and frequency	– Smaller ships (more trips, thus increased costs and emissions)
Pollution control			
– Enhance treatment works	– Potentially expensive	– Reduce volume of effluents to treat (e.g., by charging discharges) – Catchment management to reduce polluting runoff	– Requires management of diffuse sources of pollution

Flood management			
– Increase flood protection (levees, reservoirs) – Catchment source control to reduce peak discharges	– Expensive; potential environmental impact – Most effective for small floods	– Improve flood warning and dissemination – Curb floodplain development	– Technical limitations in flash-flood areas, and unknown effectiveness – Potential major political problems

Most of these strategies are being adopted or considered in many countries in the face of increasing demands for water resources or protection against risk. These management strategies also are potentially feasible in the face of climate change. Nowhere, however, are water management actions being taken explicitly and solely to cope with climate change, although in an increasing number of countries climate change is being considered in assessing future resource management.

The continuing debate in water management (Easter et al., 1998) is between the practicalities and costs of supply-side versus demand-side options, and this debate is being pursued indepedently of climate change. The tide is moving toward the use of demand-side options because they are regarded as being more environmentally sustainable, cost-effective, and flexible (Frederick, 1986; World Bank, 1993; Young et al., 1994; Anderson and Hill, 1997). "Smart" combinations of supply-side and demand-side approaches are needed, although in many cases new supply-side infrastructure may be necessary. This is particularly the case in developing countries, where the challenge often is not to curb demand but to meet minimum human health-driven standards.

There do appear, however, to be numerous "no regret" policies that warrant immediate attention. In this context, a "no regret" policy is one that would generate net social benefits regardless of whether there was climate change. Examples include elimination of subsidies to agriculture and floodplain occupancy and explicit recognition of environmental values in project design and evaluation. The effect of successful demand-side policies is to reduce the need for supply augmentation, although they may not prevent such needs entirely if changes are large. Such policy changes represent the minimum package of "anticipatory policy changes" in response to climate change.

3.2.2 Implications of Climate Change for Water Management Policy

Water management has always adapted to change (especially following extreme events or in response to increased demand), and climate change is just one of the pressures facing water managers. Other pressures include increasing demands for water resources or protection against hazard, changing water management objectives (which recently have included increasing recognition of the importance of meeting environmental needs as well as those of off-stream demands), changing water management technologies, and altered legislative environments.

It is important to distinguish between development of adaptive options for meeting changing demands and resources and assessment of the abilities of a given water management agency (interpreted broadly) actually to adapt to climate change. Over the years, a wide range of adaptive techniques has been developed, largely in response to the need to meet increased demands. Broad distinctions can be drawn among “supply-side” adaptive techniques (changing structures, operating rules, and institutional arrangements) and “demand-side” techniques (which change the demand for water or protection against risk and include institutional changes as well). Examples of supply-side adaptations include increasing flood defenses, building weirs and locks to manage water levels for navigation, and modifying or extending infrastructure to collect and distribute water to consumers. Demand-side techniques include water demand management (such as encouraging water-efficient irrigation and water pricing initiatives), changing water allocations (Miller et al., 1997), and nonstructural flood management measures (such as land-use controls). Distinctions also can be drawn between anticipatory and reactive actions. The former are taken in advance of some change, the latter in response to a change. Reactive actions include short-term operational adaptations, such as temporary exploitation of new sources, and longer-term measures. A major flood or drought, for example, often triggers a change in water management. However, although many adaptive options do exist, knowledge of these options and the expertise of officials to execute them may be limited in some situations.

The optimum extent of adaptation can be characterized in terms of the benefits and costs of adaptation. The extremes of adaptation are “no adaptation” and “adaptation sufficient to eliminate all effects” (which usually is not physically possible). The optimum level of adaptation minimizes the combined costs of adaptation and residual negative effects, with the most cost-effective steps taken first.

Water managers long have had access to many techniques for assessing options and implementing adaptive strategies. However, the techniques used have changed over time and vary between countries, and they are very much influenced by institutional arrangements in place in a country. Factors that affect adaptive capacity in a country include institutional capacity, wealth, management philosophy (particularly management attitudes toward supply-side versus demand-side strategies, as well as “sustainable” management), planning time scale, and organizational arrangements (adaptation will be harder, for example, when there are many different “managers” involved or where water managers do not have sound professional guidance).

Integrated water resources management (IWRM) (Bogardi and Nachtnebel, 1994; Kindler, 2000) increasingly is regarded as the most effective way to manage water resources in a changing environment with competing demands. IWRM essentially involves three major components: explicit consideration of all potential supply-side and demand-side actions, inclusion of all stakeholders in the decision process, and continual monitoring and review of the water resources situation. IWRM is an effective approach in the absence of climate change, and there already are many good reasons for it to be implemented. Adopting integrated water resources management will go a long way toward increasing the ability of water managers to adapt to climate change.

There are three final points to make:

1. “Upstream” adaptation may have implications for “downstream” uses. In other words, the impact of climate change on one user may be very much determined by the actions of other users in response to climate change. This emphasizes the need for basin-scale management.

2. The emphasis in this section has been on managed water systems. In many countries, particularly in rural parts of the developing world, water supply is “managed” at the household level, utilizing local water sources. There is a need to look at the implications of climate change in circumstances of this type in which investment in substantial infrastructure is unlikely.

3. Adaptation to climate change to reduce vulnerability in the water sector should involve far more than just water managers. Increasing social vulnerability to water stress (in terms of drought and flood) in many parts of the world reflects a wide range of pressures, many of which are outside the responsibility of water managers. Reducing vulnerability to climate

change-induced flood and drought will require decisions about issues such as development and planning control, fiscal incentives (such as subsidized insurance or government disaster relief) to occupy (and continue to occupy after loss) hazard-prone land, and wealth enhancement.

3.3 Adaptation to Climate Change on Wetland

Most wetland processes are dependent upon catchment-level hydrology, which can prove extremely difficult to manage. Thus, adaptations for the projected climate change may be practically impossible or very limited (Gitay et al 2001; USGCRP 2000).

Potential adaptation options are also limited by the geomorphology of the system: the evolutionary time frame of the dynamics of the system can limit some options. For example, a coastal low-lying wetland system that is relatively young and has a dynamic substrate and channeling system has fewer adaptation options than an older and more stable system. In addition, adaptation options for wetlands subject to climate change and sea level rise have on the whole not been extensively addressed in the IPCC Third Assessment Report.

A major component of adaptation that needs further attention is assessment of the actual vulnerability of wetlands and wetland species and functions to climate change and sea level rise.

Where adaptation options have been addressed they have usually been linked to established socio-economic imperatives, such as the locations of settlements, infrastructure, and economically important production. In many cases the adaptation options include protection of the coast by physical structures, accommodation of change, retreating from vulnerable areas, or simply doing nothing. In some cases, however, it may become necessary to take active steps to protect wetlands. This could occur where large numbers of people rely directly on non-marine wetlands in the coastal zone or where the wetlands provide goods and services required by people in urban areas. Foremost amongst such services are fish products and fresh water. However, as these goods and services are often uncosted or not in the possession of powerful vested interests or otherwise influential groups, it is likely that little active intervention will occur.

In some instances, the wetland habitats could be relocated or become re-established, although it is likely that in many cases this option will be limited by major natural and infrastructural physical constraints.

The recent IPCC reports suggest a small number of generic potential adaptation options that can contribute to the conservation and sustainable use of wetlands (Arnell & Chunzen 2001; Gitay et al. 2001, Mata and Campos 2001, McLean and Tsyban et al 2001, Nurse and Sem et al 2001, Scott and Gupta et al 2001, Desanker and Magadza et al 2001, USGCRP 2000, Burkett and Kusler 2000). Examples, some of which have been mentioned in the regional sections above, include:

- Design of multiple-use reserves and protected areas which incorporate corridors that would allow for migration of organisms as a response to climate change. The response of some wetland species (both animals and plants) to climate change could be a range expansion or poleward movement of the species. Some of these may be invasive species (both native and alien) and could impact on the system especially through changes in the hydrology. Adaptation options in this case would have to include truncation of potential corridors or control of invasive species to limit the expansion of more competitive native or alien species, especially into wetlands that may be small and have high endemism.

- Expansion of aquaculture to relieve stress on natural fisheries, despite the fact that much past aquaculture has led to the loss of wetlands and wetland species. Such options should be implemented only if they could demonstrate a reduction in pressure on existing wetlands.

- Poleward transportation of less mobile aquatic species across watershed boundaries to cooler waters.

- Specific management in some ecosystems which could reduce pressures on wetlands. For example, in the wetlands in the Arctic, economic diversification could reduce the pressure on wildlife. Rotational and decreased use of marginal wetlands, especially in semi-arid areas, could reduce wetland and wetland biodiversity loss.

- Integration of land, water and marine area management with the aim of reducing non-climate stresses upon wetlands, for example through reduction of fragmentation of water systems, reduction of land-based pollution into marine systems such as coral reefs, or reduction of invasive species.

- Use of water control structures for some wetlands, in order to enhance particular wetland functions and address water management issues, such as securing long-term water resources for wetland conservation. It is unlikely that such steps could be taken independently of other water management decisions, such as those that will affect irrigation and potable water supplies, and they should form part of integrated river basin and water resource management.

- Development of 'setbacks' for coastal and estuarine wetlands, perhaps linked with moves to direct sediment to specific places.

- High priority management actions in wetlands that are valuable and likely to be lost or degraded, including the implementation of wetland rehabilitation and restoration projects. Wetland creation could also be usefully undertaken, but possibly not in many cases where existing infrastructure limits both the area and processes that support particular wetland types or functions.

Other adaptation options which could benefit wetlands concern the more efficient use of natural resources and the removal of policies and financial measures that work against the maintenance, and even the creation, of wetlands.

There are likely to be negative repercussions to specific adaptation options (Gitay et al. 2001). Examples include:

- The active transportation of aquatic species or "better-adapted" warm water species poleward - historical evidence suggests that this could result in the extinction of local wetland species and large changes in ecosystem processes and structure, all with economic consequences;

- Interactions resulting from increased stocking and relocation of recreational and aquacultural endeavours;

- Other negative effects related to secondary pressures from new hydrologic engineering structures.

There also may be co-benefits of adaptation measures. For example, the development of infrastructure against sea level rise in a low-lying coastal system could result in economic gains, although the relative expense of structures such as ports and trading centres that arise are unlikely to have been costed within the context of climate change.

Analyses on specific wetlands suggests that adaptation options are limited in terms of their migration,especially inland, often due to the geology and/or the human settlement and infrastructure or the cost of the operation (Bayliss et al 1998, Mapalo 1999, Turner and Streever 2001).

An alternative management strategy is the restoration and rehabilitation of riverine wetland areas to enable large areas of land to be flooded during extreme discharges.

Another important adaptation strategy is the prevention of additional stress that can reduce the ability of wetlands to respond to climate change. Reducing pollution, avoiding vegetation removal, and protecting wetland biological diversity and integrity are viable activities to maintain and improve the resiliency of wetland ecosystems so that they continue to provide important services under changed climatic conditions.

Another important adaptation strategy is preventing the fragmentation of wetlands. Connectivity between ecosystems allows migration of species to occur in response to climate change and the maintenance of migration routes constitutes a wise approach. Maintaining river flow characteristics, including low flows also represents an important approach to maintain wetland systems.

The ability to adapt will vary from country to country depending on the available human and financial resources. Adaptive capacity is a function of socio-economic, political and legal conditions. However, poorer countries may benefit by introducing a lesser degree of alteration in their natural systems. Among the most at risk are communities with limited options for adaptability; where climatic changes add to existing stresses; already exposed to natural hazards; in the lower income groups; whose welfare, livelihood, subsistence, economies depend on wetlands, a vulnerable sector.

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