MEKONG RIVER COMMISSION

THE COUNCIL STUDY

The Study on the Sustainable Management and Development of the Mekong River Basin, including Impacts of Mainstream Hydropower Projects

Climate Change Report

Climate Change Impacts for Council Study Sectors

(Draft Final Report V2.1)

Prepared by: CCAI and Council Study Core Team

December 2017

Disclaimer:

These Council Study reports are considered final drafts prepared by the technical experts and specialists of the Mekong River Commission, through a process of consultation with representatives of member countries. The contents or findings of the reports are not necessarily the views of the MRC member countries but will serve as knowledge base and reference in the work of the MRC and its member countries in their ongoing technical and policy dialogues in ensuring the sustainable development of the Mekong river basin.

The MRC is funded by contribution from its member countries and development partners of Australia, Belgium, European Union, Finland, France, Germany, Japan, Luxembourg, the Netherlands, Sweden, Switzerland, the United States and the World Bank.

Document history

Version	Revision	Description	Issue date	Issued by
1	0	Draft outline of Output 1.3 Climate Change Report to show progress on final report following suggested format of core team	17 March 2017	Cong/Green
1	1	Updates for new outputs available for Main Scenario Work M3 CC	20 April 2017	Cong/Green
1	2	Updates for results available in May	31 May 2017	Cong/Green
1	3	Updates for results available in June	23 June 2017	Cong/Green
1	4	Updates for results available in July	31 July 2017	Cong/Green
1	5	Updates for results available	25 Oct 2017	Cong/Green
2	0	Draft Final after 9th RTWG comment and update from sectoral and discipline analyses	2 December 2017	Cong/Green
2	1	Final Draft after 10th RTWG, Forum and written comments from member countries	31 December 2017	Cong/Green

Key Messages Related to Climate Change

Hydrological and Climatic Impact

Three climate scenarios to 2040 have been tested in the study. Each scenario has similar increases in temperatures but differing changes in rainfall which is where the main uncertainty for climate change prediction lies relating to water resources. The three scenarios tested are designed to cover the possible range of likely change assuming a medium level of greenhouse gas emissions (RCP4.5). The expected sea level rise is also included and is similar for each climate scenario.

The changes in mean flows are dominated by the changing water infrastructure in the study scenarios but variability between years such as in a peak flood are strongly influenced by climate change.

Social Impact

Various aspects of social impact are apparent including the number of people affected by flood or drought. However, the indicator that best summarises the impact is food security, which takes account of the differing response of crops and fisheries to changes in the river regime. Food surplus approximates the capacity to manage and adapt to acute food shortages. Increased surpluses correspond with increased capacity. The changes from climate change are generally negative with the impact on fish in the Tonle Sap lake for the dry scenario having the most deleterious impact. The crop modelling assumed a positive impact of increased atmospheric CO_2. Translation to field conditions remains uncertain however.

In general food sufficiency is adequate in an average year, but in a critically dry year any significant reduction with climate change could cause significant problems for the poorest households and an additional strategy to alleviate this will be needed.

Economic Impact

The macroeconomic study considers the effect of different scenarios on a range of issues such as overall GDP, employment and the impact of different sectors. the most striking finding of the climate change scenarios is that there is a significant reduction in the future GDP for all scenarios, particularly for Cambodia and particularly if the drier scenario should materialise. Such impacts could seriously damage the prospects of Cambodia sustaining lower middle-income status.

Executive summary

Introduction

That the climate is changing within the Mekong Basin is something that most people believe to be true and the Council of the Mekong River Commission agreed that this was an urgent problem that must be addressed (Hua Hin Declaration 2010). The consequences of additional energy within the atmosphere are complex but likely to impact significantly on water resources including more extreme flood and drought events. Climate Change is thus fully integrated into the Council Study (through the main 2040 scenarios) and although not one of the Water Resources Sectors being studied, in fact Climate Change impacts will be included in the analyses of the Cumulative assessment team and by different sectors and indeed by economic, social and Biological Resource discipline teams. As there are a range of possible outcomes of the changing climate, three specific climate scenarios are included in the assessment.

This discipline study is led by the MRCS Climate Change Team and is able to draw on the extensive work of the MRCS in preparation of the emerging Mekong Adaptation and Strategy Plan (MASAP) that is being consulted on in Member Countries during 2017. The MASAP is supported by more detailed scenario analysis with a wider range of plausible climate futures to for 2030, 2060 and 2090 and the Council Study is totally consistent with the MASAP scenario analysis.

The scientific community through the International Panel of Climate have made available a large number of climate model outputs for different emission scenarios, for historic and future projections. The CCAI utilised analysis of this large set of data to firstly filter the dataset down to those that acceptably reproduced the monsoon seasonality of the Mekong. Three specific model outputs were then selected to give the full range of change possible futures representing wetter, drier or seasonal change. There is some evidence from the observations that seasonal change is occurring so that scenario is selected as the one used in the overall main cumulative scenario for 2040.

Assessment findings

The Climate Change team of the Council Study have prepared data for main and sub scenario simulations, and other CS teams have run hydrologic and impact models to determine impacts. This assessment thus draws on the findings in:

- ✓ Modelling - Hydrological, Sediment and Water Quality Assessment
- ✓ Biological Resource Assessment
- ✓ Socioeconomic Assessment
- ✓ Macro Economic Assessment.
- ✓ Flood Thematic Assessment flood areas and flood risk/damages
- ✓ Hydropower Thematic Assessment
- ✓ Land Use and Agriculture Thematic Assessment

The Climate Change assessment summary here is thus intended to bring together climate change related aspects of each discipline and Thematic sector of the Council Study.

It should be noted that the Council Study considers scenarios of change to 2020 and 2040 **only**. For Climate Change study this is an near term change and thus further and growing climate impacts can be expected in the more distant future such as 2060 and 2090 considered in other MRC studies.

Indicative results from the previous MRC studies including MASAP (Mekong Adaptation Strategy and Action Plan) would indicate that climate change can impact strongly on all sectors and that adaptation needs to be incorporated in development plans and policies. The Vietnam delta is especially vulnerable from climate change affecting higher flood and more severe droughts which at the same time being subject to the sea level rise effects. Should an overall wetter climate come in to place as predicted by some models and one of the test scenarios then the additional water resource offers an opportunity for other uses and increased hydropower production. However, there is a high risk that the number of people impacted will increase due to flood damages and shortages during times of drought.

The findings of the council study modelling is strongly linked to the physical changes proposed by each country in the main M2 and M3 scenarios. Although climate change plays a role that can be clearly identified it is secondary to the impact of the main infrastructure changes such as the hydropower dams in the tributaries and mainstream. The Climate is expected to continue to change to 2100 and beyond however whereas by 2040 the main water infrastructure will be in place.

Under the Council Study the impacts to 2040 are being examined under three bottom line approach:

1. Changes for People including Food Security, employment
2. Changes in Environment
3. Changes in Economics

Significant progress has been made in the Council Study to quantify for different scenarios not only river flow but flux of sediment and nutrients to the impact on agriculture and the environment and thus also the social dimension.

The finding of the Council Study assessments related to Climate Change Impacts are:

Hydrological and Climatic Impact

Three Climate Scenarios to 2040 have been tested in the Council Study. Each Scenario has similar increase in temperatures but widely differing changes in rainfall which is where the main uncertainty for climate change prediction lies relating to water resources. The 3 scenarios tested are designed to cover the possible range of likely change assuming a medium level of green house gas emmissions (RCP4.5). The expected sea level rise is also included and is similar for each climate scenario.

The changes in mean flows are dominated by the changing water infrastructure in the Council Study Scenarios though the climate signature is also strong by 2040 potentially reversing some of the positive aspects of development for extreme flood and drought. Variability between average and extreme conditions of flood or drought are strongly influenced by climate change.

Social Impact

Various aspects of Social Impact are apparent including damages or number of people affected by flood or drought. However the indicator that best summarises the impact is for Food Security which takes account of the differing response of crops and fisheries to changes in the river regime. The changes from climate change are generally slightly negative with the impact on fish in the Tonle Sap Lake for the dry scenario having the most deleterious impact. The crop modelling assuming a positive impact of the increased atmospheric CO2 which is uncertain at this time in field conditions.

Effect of Climate Change on Food Security								
Zone	Food	M3	CC	C2	C3	CC	C2	C3
		Surplus Above Self Sufficiency (Average)				Change in Surplus		
Zone 4 C Cambodia Kratie to Viet Nam	Fish	34%	34%	34%	32%	0%	0%	-2%
	Rice	58%	63%	57%	57%	5%	-1%	-1%
Zone 5 A Cambodia-Tonle Sap river	Fish	5%	10%	14%	5%	5%	9%	0%
	Rice	45%	53%	47%	47%	8%	2%	2%
Zone 5 B Cambodia Tonle Sap lake	Fish	57%	53%	58%	32%	-4%	1%	-25%
	Rice	88%	89%	88%	88%	1%	0%	0%
Zone 2-Main – Lao PDR	Fish	-1%	9%	18%	8%	10%	19%	9%
	Rice	43%	38%	38%	36%	-5%	-5%	-7%
Zone 3-Main - Lao PDR	Fish	11%	14%	20%	12%	3%	9%	1%
	Rice	83%	83%	82%	82%	0%	-1%	-1%
Zone 2 B-Upper Thailand	Fish	43%	42%	44%	41%	-1%	1%	-2%
	Rice	86%	85%	85%	84%	-1%	-1%	-2%
Zone 2 C-Lower Thailand	Fish	84%	83%	83%	83%	-1%	-1%	-1%
	Rice	56%	54%	54%	50%	-2%	-2%	-6%
Zone 3 B Thailand-Mainstream	Fish	85%	84%	84%	84%	-1%	-1%	-1%
	Rice	64%	62%	62%	59%	-2%	-2%	-5%
Zone 3 C Thailand-Songkhram	Fish	84%	84%	84%	82%	0%	0%	-2%
	Rice	74%	72%	72%	69%	-2%	-2%	-5%
Zone 6 A VietNam Delta - freshwater	Fish	61%	63%	64%	62%	2%	3%	1%
	Rice	63%	64%	62%	63%	1%	-1%	0%
Zone 6 B VietNam Delta - saline	Fish	55%	62%	63%	60%	7%	8%	5%
	Rice	51%	52%	51%	51%	1%	0%	0%

Table 1-1 Change in Food Security

In general food sufficiency is adequate in an average year, but in a critically dry year any significant reduction with climate change could cause significant problems for the poorest households and a strategy to alleviate this that is not already included in the current water resource plans will be needed. Climate change gives a reduction in fish and rice over and above that which would occur due to development alone.

Scenario	Rice	Fish
M1-M2	6%	-32%
M1-M3	16%	-43%
M1-M3CC	13%	-40%

Table 1-2 Overall Change in mainstream Rice and Fisheries Relative to baseline

The Council Study sectoral based approach has shown that even to 2040, a modest planning horizon for climate change, significant impacts from climate change are likely some of which are due to the transboundary impacts of water resource development coupled with the changing climate. There is a very significant socioeconomic development expected in the time horizon to 2040 including massive movement of people to urban areas and improvements in the standard of living. The study however highlights the risks to the poorer members of society that remain dependent on the natural resources as without intervention they can expect a worsening of the food security situation in climate extremes due to the combination of climate change impacts and development. The planning of development and adaptation to climate change needs to consider ways to lessen the impacts of this change and furthermore comprehensive study is needed both of climate and people.

Economic Impact

The Macroeconomic study considers the effect of different scenarios on a range of issues such as overall GDP, Employment, Impact of different sectors etc. For climate change the most striking finding is that there is a significant reduction in the future GDP for all climate scenarios but particularly for Cambodia and particularly if the drier scenario should materialise. Such impacts could seriously damage the prospects of member countries sustaining middle income status for their populations.

	Cambodia	Lao PDR	Thailand	Vietnam	Total LMB
M1 Trend	48.3	39.2	79.8	82.3	249.6
M2	41.8	35.1	73.7	82.7	233.3
M3 (No CC)	39.6	30.2	68.9	82.5	221.2
M3CC	38.5	30.3	70.4	81.3	220.5
C2 (Wet)	36.3	30	69.6	78.9	214.8
C3 (Dry)	36.2	29.9	69.9	78.7	214.7

GDP Projections (average) for 2040 in constant 2017 Prices

	Cambodia	Lao PDR	Thailand	Vietnam	Total LMB
	Average	Average	Average	Average	Average
M3CC	3%	0%	-2%	1%	0%
C2 (Wet)	8%	1%	-1%	4%	3%
C3 (Dry)	9%	1%	-1%	5%	3%

% Reduction in GDP Projections for 2040 Due to Climate Change

Linkage to Policy Implications and the Mekong Adaptation Strategy and Action Plan (MASAP)

The MASAP has 7 strategic priorities concerned with climate change:

1. *Mainstream Climate Change into regional and national policies, programmes and plans*

2. *Enhance regional and national cooperation on adaptation*

3. *Prepare transboundary and gender sensitive adaptation options*

4. *Support access to adaptation finance*

5. *Enhance monitoring, data collection and sharing*

6. *Strengthen capacity for preparation of climate change adaptation strategies and plans*

7. *Improve outreach of MRC products on climate change and adaptation.*

The Council Study has taken a broad view of sectoral developments coupled with consideration of climate change (an example of MASAP priority 1). The linkages and interdependencies between different parts of the water sector have been clearly demonstrated and climate change has been shown to be an important consideration in all sectors.

At the core of the Council Study is the development of hydropower and storage as well as irrigation. From the social, environmental and economic analysis it is clear that

a) There is a level of development that can be achieved by following through current plans for development as considered in the Council Study Scenarios

b) That aspects of this development could be utilised as adaptation to climate change

c) BUT that the measures considered will have negative as well as positive effects on people. And whilst some benefit others can be strongly hit.

d) That only by considering a larger cross sector approach can projects be properly assessed

The Council Study thus has much to contribute to the next stage of Climate Adaptation planning both in terms of technique and in the demonstration of the linkages to be considered.

There are gaps in our understanding, available data and analysis techniques. Even with a defined climate scenario there is too much uncertainty over how systems respond including the Tonle Sap Lake, fisheries, geomorphology of the rivers and coast under reduced sediment and further efforts are needed to close these gaps. For analysis of extremes the time series available is short and should be extended to tp present day (giving 9 years of additional data).

Better information on the expected changes in the floodplain are needed and the urbanisation and key infrastructure that can be expected so that the future simulations are more realistic.

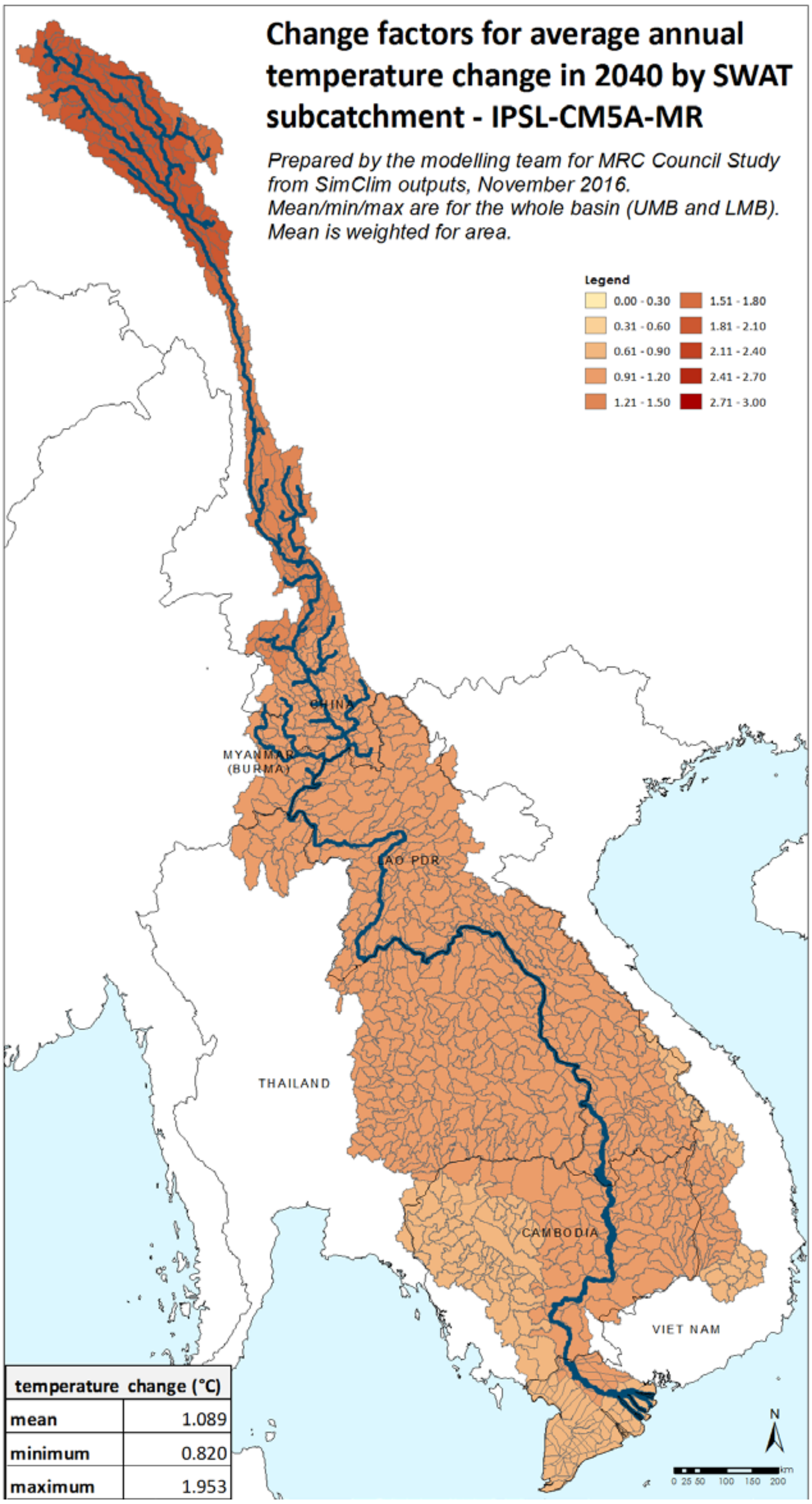


Figure 1.1 Change in mean temperature used for the Main 2040 Scenarios of The Council Study. The maximum change occurs in the Upper Basin. The 2040 the average increase in the LMB is well below the 2^{o} limit agreed at the 2016 Paris Summit but it is highly likely that temperature will continue to rise after 2040 even if emission increases are controlled by this time.

Contents

Tables

Figures

Abbreviations and acronyms

AIP	:	Agriculture and Irrigation Programme (of the MRC)
BDP	:	Basin Development Plan
BDP2	:	BDP Programme, phase 2 (2006 –10)
BDS	:	(IWRM-based) Basin Development Strategy
BioRA	:	Biological resource assessment team (under Council Study)
CCAI	:	Climate Change and Adaptation Initiative (of the MRC)
DMP	:	Drought Management Programme (of the MRC)
EP	:	Environment Programme (of the MRC)
FMMP	:	Flood Mitigation and Management Programme (of the MRC)
FP	:	Fisheries Programme (of the MRC)
IKMP	:	Information and Knowledge Management Programme (of the MRC)
IWRM	:	Integrated Water Resources Management
ISH	:	Initiative for Sustainable Hydropower (of the MRC)
JC	:	Joint Committee (of the MRC)
LMB	:	Lower Mekong Basin
LNMC	:	Lao National Mekong Committee
M&E	:	Monitoring and evaluation
MIWRMP	:	Mekong Integrated Water Resources Management Project (of the MRC)
MRC	:	Mekong River Commission
MRCS	:	Mekong River Commission Secretariat
MRC-SP	:	MRC Strategic Plan
MWRAS	:	Mekong regional water resources assistance strategy (of the World Bank)
NIP	:	National Indicative Plan (C-NIP: Cambodia, L-NIP: Lao PDR, T-NIP: Thailand, V-NIP Viet Nam)
NMC	:	National Mekong Committee
NMCS	:	National Mekong Committee Secretariat
NAP	:	Navigation Programme (of the MRC)
PMFM	:	Procedures for Maintenance of Flow on the Mainstream
PWUM	:	Procedures for Water Use Monitoring
RDA	:	Regional distribution analysis
TCU	:	Technical Coordination Unit (of the MRCS)
TNMC	:	Thai National Mekong Committee
TRG	:	Technical Review Group (of the MRC)
UMB	:	Upper Mekong Basin
VNMC	:	Viet Nam National Mekong Committee

1 Introduction

1.1 Purpose of this report

The purpose of this report (Output 1.3) is to present the key findings of the Climate Change aspects of the MRC Council Study. The Assessment integrates the findings of the social, economic and environmental assessments to identify the key impacts and benefits of selected water resources developments. Climate Change is mainstreamed into the Council Study through the choice of the main scenarios that include with and without climate change impact in 2040 for one possible mid range climate scenario. To avoid repetition the assessments in each Thematic Area this report concentrates on the key issues relating to climate change only and further details as relating to the each sector and discipline are given in the relevant volumes.

The agreed scope of the report as set out in the Council Study Inception Report (MRC 2014) is*: 'the Council Study will assess how a changing climate may exacerbate (increase) or mitigate (reduce) some of the impacts caused by changes in water use, in essence it will identify the risks and opportunities that Climate Change provides in the context of developments in the six thematic areas selected for the study.*

This output will result in an enhanced, higher-confidence assessment of how climate change will change the positive and negative impacts of water resources developments and infrastructure within the six selected thematic areas on the triple-bottom-line. The impacts of water resource development and infrastructure will be further analysed in the context of climate change to assess opportunities and risks.

Each thematic area assessment will include considerations of a changing climate (according to the best available knowledge of such changes) in order to better understand the impact of climate change may have on the social, environment and economic conditions of the basin, and assess whether changes in precipitation, temperature and extreme meteorological events and sea level rise will exacerbate or mitigate the impacts.

The findings of the Council Study assessment are being presented in three ways: Firstly, in terms of impacts on people (social), the economy (economic) and the environment. Secondly, according to thematic areas (this report), Thirdly, in terms of trade-offs, synergies and other forms of interaction. In all cases an effort is made to separate the effects of water resources development from other exogenous processes.

1.2 Report contents

The report describes the overall cumulative development scenarios, the sub scenarios for Climate Change and the assessment indicator framework used. The main body of the report is given to the presentation of the findings and further details on status and background are given in Appendices.

The report links together with other Council Study Volumes:

1. Summary and Cumulative Impact Assessment
2. Thematic Report 1: Irrigation
3. Thematic Report 2: Non Irrigated Agriculture and Land Use Change
4. Thematic Report 3: Domestic and Industrial Water and sand mining
5. Thematic Report 4: Flood Protection Structures and Floodplain Infrastructure
6. Thematic Report 5: Hydropower Development
7. Thematic Report 6: Navigation
8. Discipline Report: Social and Economics Assessment
9. Discipline Report: Modelling: Hydrological Assessment, Geomorphology and Sediment Modelling, Nutrient Modelling and Assessment
10. Discipline Report: Biological Resource Assessment (BioRA)
11. **Discipline Report: Climate Change (this report)**

2 Design of the assessment

The Council Study Assessments follows the principles of IWRM in considering the different linked sectoral changes. Although changes throughout the basin are being considered it is the impacts along and close to the Mekong River that is considered as the 'Impact Zone' for analysis as shown in Figure 2.1. This is based on an expected corridor of 15km from the main river and in main tributaries close to the main river where the livelihood of people is closely linked to the river.

The Council Study has available continuous simulation modelling that covers a period of 26 years which can be used for statistical analysis of floods and drought for future possible climates and development scenarios.

2.1 Process

The assessment for climate change are not separated from the assessment work for each sector and the cumulative impact but do focus the relevant findings of each sector and present them as relevant for the fits with the overall Council Study cumulative assessment and discipline team outputs as shown in Figure 2.1.

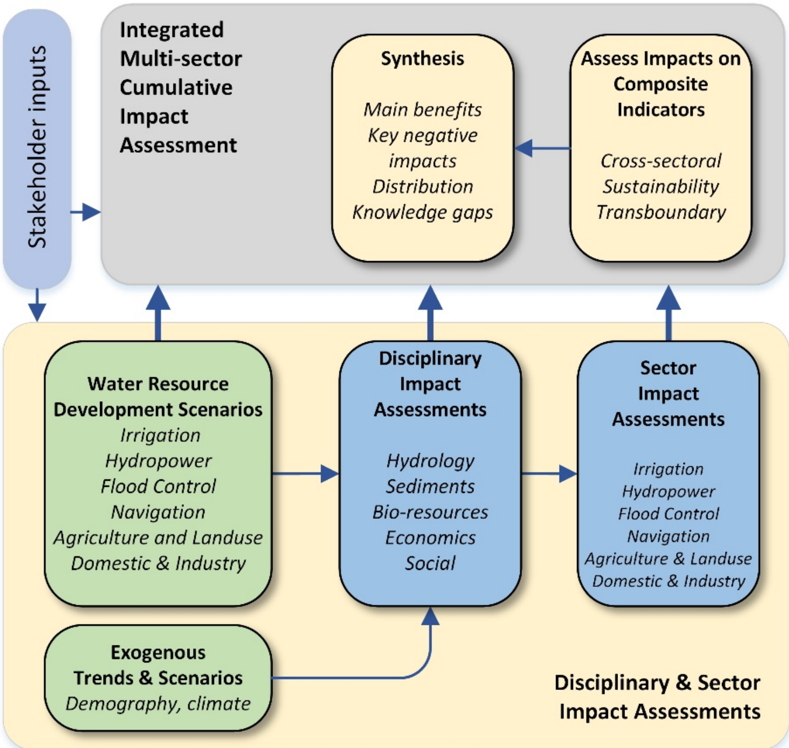


Figure 2.1 Sector Analysis of the Council Study. Climate Change is classified as an exogenous change but is subject to specific analysis given the importance to water resources

Figure 2.2 Council Study Impact Zone in the Lower Mekong Basin (LMB). Climate change scenarios are applied to the whole basin including the upper part.

2.2 Climate Change Scenarios

2.2.1 Approach to define basin-wide climate change scenarios for the LMB

Although the historic changes in climate can be demonstrated using those stations with long records, for the future projection of change the trend may continue, accelerate or decline depend on the world community response to the challenge of control the anthropogenic influence on world climate. In order to assess the impact of climate change on the basin, scenarios climate change need to be defined. Extensive consultation on this issue was carried out by the MRC Climate program and thus for the Council Study a subset of the Climate Change Scenarios is selected.

Scenarios are needed following requirements:

- Provide information on available projections of future climate and their uncertainty;
- Provide scenarios for assessment of potential impacts and vulnerability to climate change in different sectors and to different stakeholders (e.g. water resources, agriculture, fisheries, hydropower, fluvial and coastal flooding, ecosystems, health, socio-economic impacts, etc.); and
- Provide climate information for preparation of adaptation strategies and action plans as well as implementation of local demonstration sites for climate change adaptation.

The scenarios are defined by using an IPCC' approach that based on GCM, greenhouse gas emission and climate sensitivity. Following the principles set out above the below criteria will be considered in selection of the GCMs for climate change scenarios:

- The selected GCMs together must cover a range of different projected changes in both magnitudes and climate patterns so as to represent the range of uncertainty inherent in the GCM climate change projections for the LMB. The changes in climate patterns include for example wetter wet seasons, wetter over the whole year, drier over the whole year, drier wet seasons, increased seasonal variability (i.e. wetter wet seasons and drier dry seasons), etc.
- To choose between two equally performing models, the GCM which contains a full set of climate variables (precipitation, temperature, solar radiation, relative humidity and, if possible, sea level rise as well), all emission scenarios, climate sensitivity settings and time horizons are preferred.

Approach for GCM selection and development of climate change scenarios under MRC Climate Program (formerly CCAI)

The approach for selecting a small number of GCMs (by CCAI) that met the criteria described above and for developing climate change scenarios that meet the needs of basin-wide assessment of climate change impacts and planning for adaptation in the LMB involved the following five stages:

Stage 1. Obtain a dataset of climate change projections that:

- covers all up-to-date GCM outputs and emission scenarios and is easily updateable;
- is affordable in terms of time and finance required to downscale, extract and analyse the climate change projection information that include quantification of uncertainty;
- is able to be stored, accessed and transferred across the MRC, its member countries and other stakeholders.

Stage 2. Shortlist the well performed GCMs using literature review. The well-performed GCMs are those have been found simulating satisfactorily the most influencing climate processes in the Asian monsoon region that contains the LMB.

Stage 3. Check from the dataset obtained in Stage 1 whether outputs of the shortlisted GCMs contains a full set of climate variables (precipitation, temperature, solar radiation, relative humidity and if possible sea level rise), all emission scenarios, climate sensitivities, time horizons, seasons and locations. Also, check that no errors or abnormal outputs exist when projected changes are extracted for all the different emission scenarios, climate sensitivities and time horizons.

Stage 4. Select three GCMs that together cover the whole range of projected changes in terms of both magnitudes and climate patterns. The selection is made by classifying and ranking the outputs of shortlisted GCMs (obtained from the dataset collected in Stage1). The outputs are investigated for three regions: lower (LMB), upper (UMB) and whole Mekong Basin (MRB)), various emission scenarios, climate sensitivities, time horizons and seasons. This also includes a sensitivity analysis to check on the influence of emission scenarios, sensitivity settings, time horizons on the ranking of the shortlisted GCMs.

Stage 5. Formulate recommendations on a number of basin-wide climate change scenarios for the LMB. Consequently, the basin-wide climate change scenarios for the LMB are defined such that the two criteria for GCM selection and the needs of MRC are met.

Selection of GCMs, emission scenarios, and climate sensitivity settings

There are three main sources of uncertainty associated with GCM-based climate change scenarios: (1) GCM uncertainty, (2) emission scenario uncertainty and (3) climate sensitivity uncertainty. In order to determine which of the three main sources of uncertainty is the most significant for the LMB, the obtained dataset of climate change projections derived from SimCLIM software is used to quantify the uncertainty.

The result shows that uncertainty associated with the different GCMs is the most significant source of uncertainty. Therefore, the GCM selection part of the climate change scenario development procedure is the most important. The remainder of this part, therefore focuses on the selection of GCM and then also provides recommendations for which emission scenario and climate sensitivity settings should be used for.

The selected GCMs need to represent a range of different climate change projection and their dataset are available. Based on these criteria, the following three GCMs are selected:

- **IPSL-CM5A-MR** as the 'medium' scenario since it projects wetter wet seasons and drier dry season (i.e. increased seasonal variability). It is the change simulated from this GCM that is used in the main M3CC simulations;
- **GFDL-CM3** as the 'upper' bound of projected future impacts (in most of the LMB this model gives a projection of wetter overall conditions).
- **GISS-E2-R-CC** as the 'lower precipitation' bound of projected future impacts (i.e. drier overall, especially in the wet season which is important since if wet season flow decreases it will be a big concern for MRC member countries);

Three (3) magnitudes of climate change due to low, medium and high future scenarios of carbon emission, i.e. greenhouse gas emission pathways RCP 2.6, RCP 4.5 and RCP 8.5, represent for low, medium and high level of the emission (Figure 2.3). Nine (9) basin-wide climate change scenarios were thus used for the more comprehensive assessment of Climate Change by the MRC's former Climate Change Adaptation Initiative (CCAI) which included a basin-wide climate change impact assessment of potential changes to 2060.

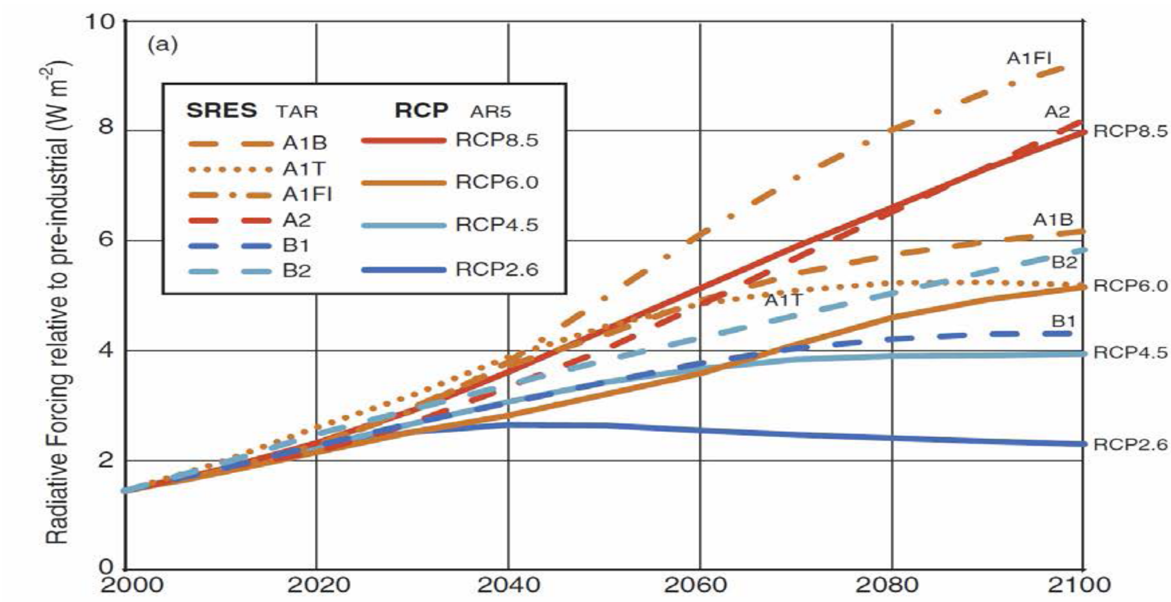


Figure 2.3: Greenhouse gas emission scenarios (RCP 4.5 is used for Council Study)

2.2.3 Selection of climate change scenarios for Council Study

Due to limitation of time and other resources, only three climate change scenarios are selected for climate change impact assessment within the Council Study. Because the GCM is most important sources of uncertainty, all 3 selected GCM are used to assess the impacts and the medium level is chosen amongst 3 level of emissions. These proposed climate change scenarios are shown in Table 3. Because the time horizon of change considered in the Council Study is 2040 it should be noted that Climate Change Impacts can be expected to increase after 2040 even if gas emmisions are stabilised.

Table 3: Three selected climate change scenarios for Council Study

No.	Type of scenarios		Emission scenarios	GCM	Climate sensitivity
	Level of change	Pattern of change			
Medium climate change scenarios					
1(M3CC)	Medium	Increased seasonal variability wetter wet and drier dry seasons	RCP4.5	IPSL-CM5A-MR	Medium
C2		Wetter overall		GFDL-CM3	
C3		Drier overall		GISS-E2-R-CC	

Defined sea level rise scenarios

The approach for sea level rise scenarios is to apply projections of total sea level rise for an offshore location close to the Mekong Delta (e.g. longitude 106.75 and latitude 9.25 (decimal degrees)). Ideally, the sea level rise projections would be obtained for all three GCM models selected. However, of the three selected GCMs only two (GFDL-CM3 and GISS-E2-R-CC) have sea level information available in the MRC climate change projections dataset. The analysis shows that there is very little difference in the sea level change factors obtained from the GFDL-CM3 and GISS-E2-R-CC GCMs and therefore it is recommended that one set of values for sea level rise scenarios for can be used. The details of the sea level rise scenarios are shown on Table 4.

Table 4: Three sea level rise scenarios for CCAI basin-wide assessments and Council Study (m)

Sea level rise scenarios	2030 (2021-2040) Metre rise	2040 Council Study Metre rise	2060 (2031-2070) metre	2090 (2081-2100) metre
Low (RCP 2.6)	0.13	Not used in CS	0.30	0.46
Medium (RCP4.5/ 6.0)	0.15	**0.21**	0.33	0.57
High (RCP 8.5)	0.16	Not used in CS	0.40	0.75

2.3 Formulation of development scenarios

The Member Countries of the LMB agreed to assess the following main development scenarios:

- Early Development using estimates of physical/socio-economic condition as of 2007
- Definite Future Scenario using a projected physical/socio-economic condition as of 2020
- Planned Development Scenario using a projected physical/socio-economic condition as of 2040

2.4 Development Sub Scenarios

2.4.1 Formulation of ‘Main Scenarios”

2007 – Early Development Scenario

The SWAT, IQQM and ISIS models reflecting the 2007 situation are available with IKMP as they were used for simulation runs for CCAI in the past. These models have been checked and modified if necessary to incorporate any more recent improvements that have been made to the model, for example to improve channel representation, that are not related to infrastructure or floodplain development.

2020 Definite Future Development Scenario

The SWAT, IQQM and ISIS models were updated during the last years to accommodate the latest developments in flood protection works and roads. The models reflect the situation in 2014 and are used for the Initial Studies as reference situation. In 2013 a special survey was carried out in Cambodia to have updated levels of the NR 6A, 8, 1 and 2.

As no additional information on floodplain development or flood protection works was received from the MCs for future plans the 2014 version will be used for the 2020 Definite Future Development Scenario. The models providing upstream inputs to the ISIS model will be updated to include the Dams which are planned to be constructed and to be in operation by 2020.

2040 – Planned Development Scenario

Due to the limited additional information provided by MCs for future plans it is proposed that the PDS-2040 scenario be based upon the work currently being carried out under task 3 of the Initial Studies project. In October and November 2015 a second and third round of workshops were held for Initial Studies in order for teams of the MCs to produce draft development plans for the year 2060. In these plans future developments of various sectors are presented in an integrated manner. A 2040 Development Scenario for the Council Study can be formulated based on the results of the workshops. In addition to the floodplain developments identified by the Initial Study upstream developments such as dams which are planned to be constructed and in operation between 2020 and 2040 will be included in the hydrological models.

Information on flood protection works and floodplain infrastructure relevant to the 2000, 2007, 2020 and 2040 scenarios will be provided to IKMP for incorporation in the various hydrologic and hydraulic models used to simulate daily flow behaviour across the Lower Mekong Basin (LMB).

1960 – Historic Development Scenario

In addition to the abovementioned development scenarios, the following two development scenarios listed in Table 2 be considered for assessment as per agreement by the Member Countries during the Small Technical Workgroup Meeting on Reference Scenario. For additional details, the reader is referred to the Draft Working Paper on Reference Scenario and Meeting Minutes which are available in the Council Study Team Site. It should be noted that the assessment of the 1960 development scenario will focus on impacts on flow and sediment.

Table 4 Main water resources development scenarios for Council Study.

	Scenario	Level of Development for water-related sectors*						Climate	Flood-plain settlement
		ALU	DIW	FPF	HPP	IRR	NAV		
M1	Early Development Scenario 2007	2007	2007	2007	2007	2007	2007	1985-2008	2007
M2	Definite Future Scenario 2020	2020	2020	2020	2020	2020	2020	1985-2008	2020
M3-NoCC	Planned Development Scenario 2040	2040	2040	2040	2040	2040	2040	1985-2008	2040
M3	Planned Development Scenario 2040	2040	2040	2040	2040	2040	2040	Mean warmer & seasonal	2040

*ALU = Agric/Landuse Change; DIW = Domestic and Industrial Water Use; FPF = flood protection infrastructure; HPP = hydropower; IRR = irrigation; and NAV = Navigation

2.4.2 Formulation of "thematic climate change sub-scenarios"

Three sub-scenarios for 2040 are being prepared to explore the interactions between water resource development and changes in climate (Table 6). To help better understand the overall effects of climate change, the M3-NoCC was introduced within the main scenarios with no climate change against which other scenarios may be compared as this was of importance to other sectoral study results. The sub-scenarios which assume climate changes (C2, and C3) are thus giving likely variability but for CS as model variability is the key source of uncertainty the global circulation models outputs selected are driven with assumptions of intermediate levels of greenhouse gas emissions (RCP4.5).

Table 5: Climate change sub-scenarios for analysis CIA.

	Climate	Description	Sectors
M3CC	Increased seasonal variability to 2040 (IPSL-CM5A-MR)	Planned Development 2040 + More seasonal Climate in 2040	2040 dev. scenarios
M3-NoCC	No CC (1985 – 2008)	Planned Development 2040 No climate change	2040 dev. scenarios
C2	Wetter (GFDL-CM3)	Planned Development 2040 + Wetter Climate in 2040	2040 dev. scenarios
C3	Drier (GISS-E2-R-CC)	Planned Development 2040 + Drier Climate in 2040	2040 dev. scenarios

2.5 Assessment methods

Comparisons between sub-scenarios (C2, C3 and M3) with climate change and sub-scenario (C1) without climate change (Table 6) are used to assess the climate change impacts.

Table 6: Climate impact assessment framework

Comparison	Hydrological	Sediments	Bio-resources	Economic	Social
C2 vs C1	**X**	**X**	**X**	**X**	**X**
C3 vs C1	**X**	**X**	**X**	**X**	**X**
M3 vs C1	**X**	**X**	**X**	**X**	**X**

Besides, the sub-scenarios of flood protection will be examined together with climate change scenarios to identify the potential flood protection measure to adapt with climate change.

2.6 Strategic indicators

The Strategic Indicators must take account of the triple bottom line assessment and other sector analysis in the CS. For

Table 8   Candidate composite strategic indicators for use in the Cumulative Impact Assessment based on selected indicators from the disciplinary assessments.

Dimension	Composite Strategic Indicators	Disciplinary assessment Indicators
Social	Wellbeing	Water security Food security Income security Health security
	Employment	Employment in MRC sectors Employment satisfaction
	Social cohesion	Public participation Trust and public acceptance Social capital
	Equality	Gender inequality Income equality
	Resilience	Total flood protected area Total water storage Total irrigated area
Environmental	Water flow conditions in mainstream	Dry season flows – PMFM compliance Flood season peak flows – PMFM compliance Tonle Sap reverse flows – PMFM compliance Timing of onset of wet season flows Annual flooding
	Water quality and sediment conditions in mainstream	Mainstream water quality – PWQ compliance Sediment transport in the mainstream Salinity intrusion in the delta
	Status of environmental	Wetland area

Dimension	Composite Strategic Indicators	Disciplinary assessment Indicators
	assets	River channel conditions and habitats River bank erosion risk Aquatic biodiversity Ecologically significant areas
Economic	Net economic value of MRC sectors	Economic value of irrigated agriculture, recession agriculture, rainfed agriculture, hydropower production, flood damage, drought damage, capture fisheries, etc. Economic expenditure on tourism and recreation
	Contribution to national economy	Proportion of MRC sectors to overall GDP
Integrated	Resource sustainability	Economic value of sectors Wellbeing Employment Water flow Water quality Environmental assets
	Cross-sectoral synergies	Economic value of sectors Social cohesion Equality Resilience
	Transboundary balance	Water flow Water quality Environmental assets Economic value

3 Simulation and Assessment Results

3.1 Available Data

The full data for model and assessment outputs is presented in the Modelling Report documentation, and for Biological Resource Assessment and Socioeconomics and Macro economics in the relevant volumes so here only the highlights relating to climate change will be presented. The 2020 Scenario is too close to the current day so climate change is not incorporated into the simulation thus this study concentrates on the results at 2040 compared with the baseline M1 Scenario.

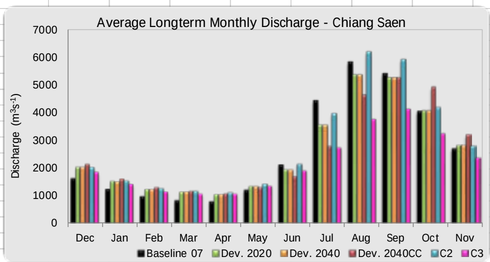
Because the M3 results incorporate development of extensive development the changes due to climate change must be viewed relative to this 'built in' change. Each result is the average of 24 years of simulation in the IQQM or ISIS model.

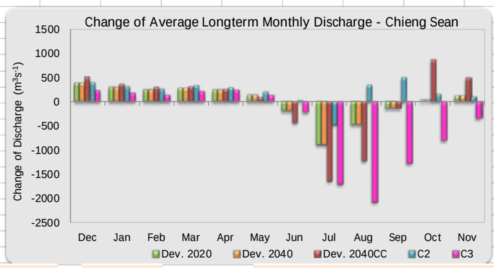
3.2 Scenario Results

3.2.1 *Changes in Average Flows – Yearly*

The simulation results for changes in average flow in the Chiang Saen to Kratie Reach for scenario M3-CC relative to M1 (2007) are shown in the Table below. The flow changes are however linked not only to climate change but also to development and thus the results of M3-NoCC are needed to determine the climate change aspect.

Table 3-1 Average Flow Change Main and Climate Scenarios – Chiang Saen



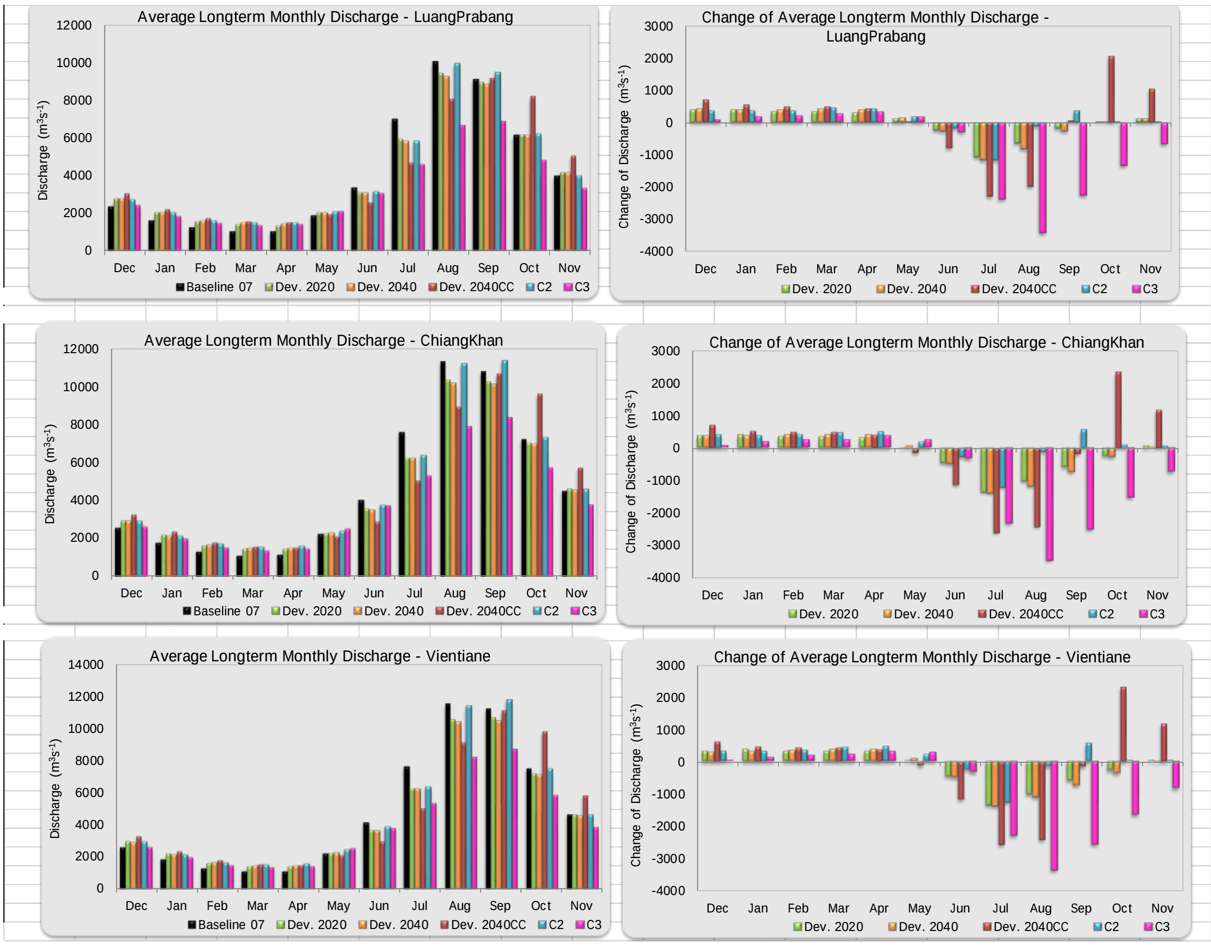


Average Longterm Monthly Discharge - Chiang Saen

	Baseline 07	Dev. 2020	Dev. 2040	Dev. 2040CC	C2	C3
Dec	1642.6	2028.9	2028.2	2142.9	2042.0	1865.3
Jan	1241.6	1533.8	1532.5	1602.2	1545.3	1420.8
Feb	1002.0	1244.0	1242.4	1292.0	1259.7	1146.9
Mar	860.2	1144.8	1143.4	1172.1	1187.4	1068.7
Apr	826.6	1074.3	1072.9	1092.8	1119.8	1063.1
May	1225.4	1355.2	1354.4	1316.3	1439.5	1370.7
Jun	2135.6	1942.3	1940.5	1698.9	2169.2	1900.2
Jul	4435.0	3555.7	3554.4	2796.8	3972.6	2736.2
Aug	5844.4	5376.4	5376.1	4617.9	6196.0	3767.1
Sep	5403.1	5270.3	5268.5	5263.6	5911.1	4135.7
Oct	4050.2	4077.2	4076.3	4914.9	4198.0	3257.3
Nov	2710.2	2826.9	2825.4	3190.1	2806.4	2362.9
Wet season	4096.4	3841.5	3840.2	3747.0	4208.9	3026.5
Dry season	1133.1	1396.8	1395.7	1436.4	1432.3	1322.6

Change of Average Longterm Monthly Discharge - Chieng Sean

	Dev. 2020	Dev. 2040	Dev. 2040CC	C2	C3
Dec	386.3	385.6	500.3	399.4	222.7
Jan	292.2	290.9	360.6	303.7	179.2
Feb	242.0	240.4	290.0	257.7	144.9
Mar	284.6	283.2	311.9	327.2	208.5
Apr	247.7	246.3	266.2	293.2	236.5
May	129.7	129.0	90.9	214.1	145.2
Jun	-193.3	-195.1	-436.7	33.5	-235.5
Jul	-879.3	-880.6	-1638.2	-462.4	-1698.8
Aug	-467.9	-468.3	-1226.4	351.6	-2077.3
Sep	-132.7	-134.6	-139.4	508.0	-1267.4
Oct	27.0	26.1	864.7	147.8	-792.9
Nov	116.7	115.2	479.9	96.2	-347.3
Wet season	-254.9	-256.2	-349.4	112.5	-1069.9
Dry season	263.7	262.6	303.3	299.2	189.5



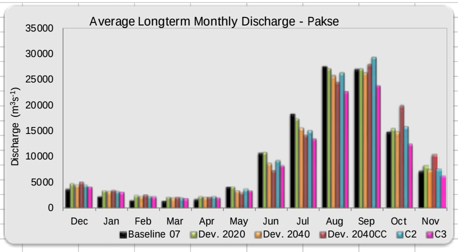
It is interesting to note that relative to M3-CC that without climate change the increases in dry season flows are much greater whereas in the wet season the decreases are high during the early months of May to August when dams are refilling but there is less change for the later part of the wet season. There is thus a clear difference between scenarios related to climate change. The effect at Chiang Saen is probably most sensitive to climate assumptions due to the snow melt and glacier changes.

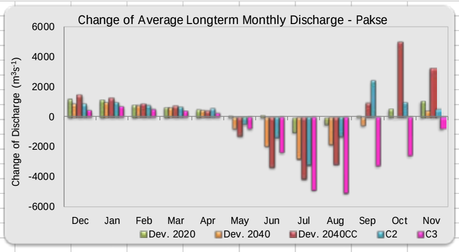
Chieng Sean	Dev. 2020	Dev. 2040	Dev. 2040CC	C2	C3
Dec	23.5	23.5	30.5	24.3	13.6
Jan	23.5	23.4	29.0	24.5	14.4
Feb	24.2	24.0	28.9	25.7	14.5
Mar	33.1	32.9	36.3	38.0	24.2
Apr	30.0	29.8	32.2	35.5	28.6
May	10.6	10.5	7.4	17.5	11.9
Jun	-9.1	-9.1	-20.5	1.6	-11.0
Jul	-19.8	-19.9	-36.9	-10.4	-38.3
Aug	-8.0	-8.0	-21.0	6.0	-35.5
Sep	-2.5	-2.5	-2.6	9.4	-23.5
Oct	0.7	0.6	21.3	3.7	-19.6
Nov	4.3	4.2	17.7	3.6	-12.8
Wet season	-6.2	-6.3	-8.5	2.7	-26.1
Dry Season	23.3	23.2	26.8	26.4	16.7

Vientiane	Dev. 2020	Dev. 2040	Dev. 2040CC	C2	C3
Dec	12.2	11.2	24.1	12.2	0.0
Jan	20.8	16.1	25.5	16.5	6.5
Feb	23.6	25.4	33.5	26.6	14.0
Mar	27.7	33.3	38.9	37.9	19.7
Apr	26.6	33.6	34.3	41.4	28.8
May	0.9	4.0	-5.1	10.1	12.9
Jun	-11.1	-11.9	-27.7	-6.1	-8.1
Jul	-17.7	-18.1	-33.9	-16.3	-30.0
Aug	-8.6	-9.7	-20.9	-1.3	-29.1
Sep	-5.2	-6.6	-1.3	5.1	-22.8
Oct	-3.7	-4.8	30.8	0.5	-22.2
Nov	0.6	-0.7	25.5	0.1	-17.5
Wet season	-7.8	-8.8	-6.0	-2.2	-23.6
Dry Season	16.1	17.3	22.0	20.4	11.1

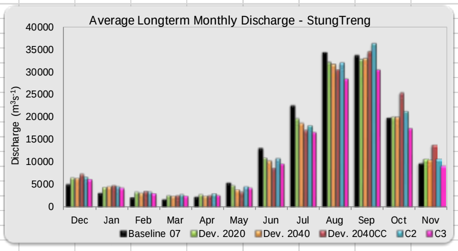
Table 3-2 Percentage Change in Long Term Average Flow - Chiang Saen and Vientiane

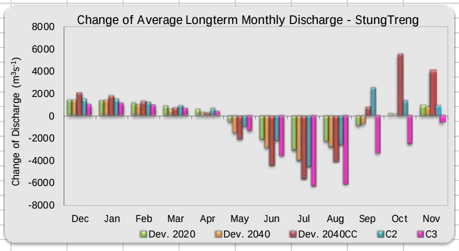
Further down the basin the pattern is repeated with the dry season averages uplifted and wet season average flows reduced.





Pakse	Dev. 2020	Dev. 2040	Dev. 2040CC	C2	C3
Dec	31.2	22.8	39.8	23.6	12.5
Jan	46.9	41.4	53.7	41.2	30.3
Feb	47.6	43.6	53.8	44.6	29.9
Mar	44.1	41.2	50.2	43.1	25.5
Apr	27.5	24.3	24.6	29.6	14.5
May	2.2	-18.8	-29.9	-11.7	-18.4
Jun	1.3	-18.1	-31.1	-12.5	-22.0
Jul	-5.3	-15.1	-22.3	-17.4	-26.2
Aug	-1.8	-6.7	-11.3	-4.7	-18.3
Sep	0.3	-2.1	3.7	9.0	-11.9
Oct	3.7	-0.5	33.9	6.5	-17.0
Nov	14.7	5.6	45.4	6.9	-11.2
Wet season	0.4	-6.4	-1.1	-1.8	-17.8
Dry Season	28.4	18.7	23.7	21.7	10.3





StungTreng	Dev. 2020	Dev. 2040	Dev. 2040CC	C2	C3
Dec	26.2	26.4	40.6	28.5	19.2
Jan	40.5	43.5	54.8	44.5	35.3
Feb	47.3	44.1	58.7	51.0	38.5
Mar	42.1	27.9	37.7	46.3	32.8
Apr	24.5	11.4	11.8	27.7	16.4
May	-9.7	-26.5	-36.4	-17.1	-23.2
Jun	-15.9	-21.5	-33.1	-17.0	-26.7
Jul	-13.3	-17.4	-24.5	-19.7	-27.1
Aug	-6.6	-8.0	-11.6	-7.3	-17.5
Sep	-2.6	-2.2	2.5	7.5	-9.8
Oct	0.9	0.5	27.7	6.7	-12.4
Nov	9.2	7.9	41.2	9.4	-6.0
Wet season	-5.4	-7.0	-2.6	-3.3	-16.5
Dry Season	22.5	15.3	20.7	23.0	13.5

The pattern of decrease in wet season flows and increase in dry season is modified by the Tonle Sap Lake which in a natural condition plays a similar role as upstream dams in storing water in the wet season and supplementing the dry season flows with the stored water. AT the beginning of the dry season the contribution to total flow downstream of the Mekong is high and thus changes in the magnitude of release are also high if the lake storage is not available.

Kratie	Dev. 2020	Dev. 2040	Dev. 2040CC	C2	C3	TanChau	Dev. 2020	Dev. 2040	Dev. 2040CC	C2	C3
Dec	25.9	40.8	24.3	26.6	15.0	Dec	9.8	21.1	8.4	7.9	-6.4
Jan	39.2	52.7	41.6	42.0	33.1	Jan	13.2	25.9	14.0	24.8	9.1
Feb	43.6	54.3	46.4	47.3	37.3	Feb	15.5	26.7	17.5	23.7	6.8
Mar	39.5	44.7	37.6	38.9	24.6	Mar	31.6	48.4	30.6	20.7	-1.9
Apr	23.9	21.0	21.3	24.3	10.2	Apr	30.5	40.9	31.1	-15.5	-39.0
May	-9.5	-28.9	-20.5	-17.3	-24.8	May	2.5	0.9	-0.3	-42.1	-47.0
Jun	-16.4	-34.2	-21.7	-17.7	-28.3	Jun	-10.3	-26.8	-12.4	-21.5	-33.0
Jul	-13.2	-25.3	-17.6	-20.3	-28.3	Jul	-15.2	-31.2	-22.7	-22.8	-34.0
Aug	-6.8	-11.7	-8.0	-8.3	-18.4	Aug	-6.1	-18.6	-8.8	-9.6	-24.4
Sep	-2.7	2.0	-2.1	7.5	-9.4	Sep	-4.9	-6.0	-6.1	-2.8	-14.7
Oct	0.7	26.8	0.9	8.8	-10.5	Oct	-4.1	0.3	-4.7	-0.1	-12.3
Nov	8.9	41.8	8.5	11.0	-4.9	Nov	-1.9	10.4	-3.6	2.5	-12.5
Wet season	-5.4	-2.5	-6.7	-3.0	-16.4	Wet season	-6.4	-9.8	-8.9	-7.1	-19.9
Dry Season	22.6	25.1	19.7	21.7	11.2	Dry Season	14.4	25.0	14.1	7.7	-7.7

Table 3-3 Comparison of Mean Monthly Flow at Kratie and Flow at Tan Chau, Note dry season increase at Tan Chau is much lower due to the effect of the Tonle Sap Lake

3.2.2 Changes in Extreme Flows – Flood

There are a number of ways in which flows can be analysed, for floods the most useful is to using frequency analysis to fit a distribution to the measured (or modelled) series and derive peak flows at given probabilities such as 20 year, 50 year and 100 year return period events (or 0.05, 0.02, 0.01 Annual exceedance). Such values can then be used in flood risk or damage calculations.

The results above are based on the changes in monthly average flows. If the highest flood flows within the scenario are considered then another picture emerges as shown below.

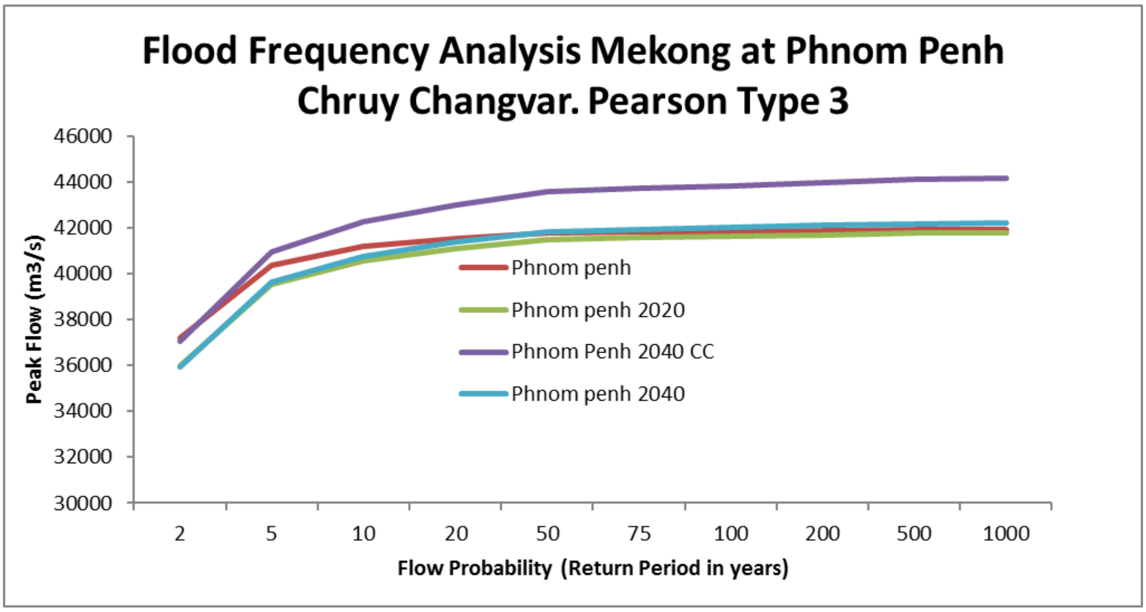
Table 3-4 Changes in Mean Annual Flood and Peak Flood Flows

Scenario	Annual Flood	Chiang Saen	Luang Prabab	Nong Khai	Mukdahan	Pakse	Stung Treng
EDS	Mean	9,651	15,902	19,282	31,382	38,183	45,843
M2	Mean	9,158	14,932	18,069	29,808	36,713	43,588
M3 (NoCC	Mean	9,158	13,879	17,372	28,972	36,463	43,622
M3 (CC)	Mean	10,252	15,439	20,356	31,800	39,683	46,734
EDS	Max	13,668	24,882	25,434	38,042	48,119	62,581
M2	Max	12,312	24,559	25,183	37,221	47,814	61,466
M3 (NoCC	Max	12,315	20,697	21,295	36,395	45,569	62,351
M3 (CC)	Max	21,913	27,419	44,696	51,515	60,997	69,770

The Mean annual flood peak shows a modest increase but the highest flood flow of the series shows much higher increase.

Downstream of Kratie

The changes downstream of Kratie follow a similar trend but are most sensitive to the change in volume. Development tends to decrease the wet season flood flows but the climate change impact is for increase in the main scenario as illustrated for Chruy Changvar Phnom Penh below. At more frequent events 2-5 years the M3 Scenario is below the M1 Baseline but at higher return periods the difference is small. For M3CC there is a shift in the higher flows though at frequent events there is little difference to the baseline.



3.2.3 Changes in Extreme Flows – Flood Damage

The impact on flood extreme changes can be calculated using the frequency analysis and known functions of water level/damage derived at a district level. These are then summated and damages on damages estimated as shown in the example below. The full information on the method applied and results are given in the accompanying Council Study Flood Sector Report.

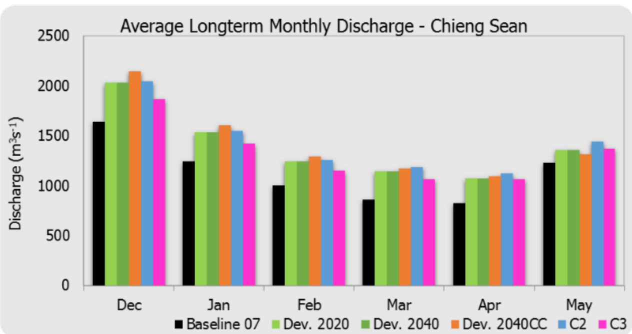
Corridor Vietnam Fresh water		Socio economic Development	Water Infrastructure	Annual Average Damage ($m)			Damage Extreme Flood Event ($m)
		Year	Year	Agriculture	Other&Urban	Total	1:100yr+
Scenario M1		2010	2007	5.4	24.8	30.2	155
Scenario M1		2040	2007	5.2	238.6	243.8	1,521
Scenario M3		2040	2040	3.5	160.6	164.1	1,171
Scenario M3 CC		2040	2040	9.5	373.2	382.7	3,187
Scenario C2		2040	2040	20.9	544.1	565.0	3,377
Scenario F2		2040	2040	9.5	63.4	72.9	3,314

Table 3-5 Example of flood damage changes with scenario - Vietnam Delta (Freshwater part). See Flood Report for full range of locations.

The results highlight not only the change in damage with climate and development but the importance of the changing value of the assets at risk of flood and the relative proportion of damages in agriculture that dominate much of the LMB for 2007 baseline, whereas in 2040 much more damage can be incurred for infrastructure, urban commercial and residential property and indirect impacts on non water parts of the economy. With development a single extreme event could give a high level of damage, around $3.3Billion estimated in the Vietnam delta assuming defences are overtopped. This may be compared with the baseline condition when only $155m is expected for a similar return period event.

3.2.4 Changes in Extreme Flows – Drought Analysis

In a monsoon climate the dry season is well defined and analysis limited to a range of months December – May. The Changes in average flow at each Key Station has been calculated for each climate scenario and results are shown below.



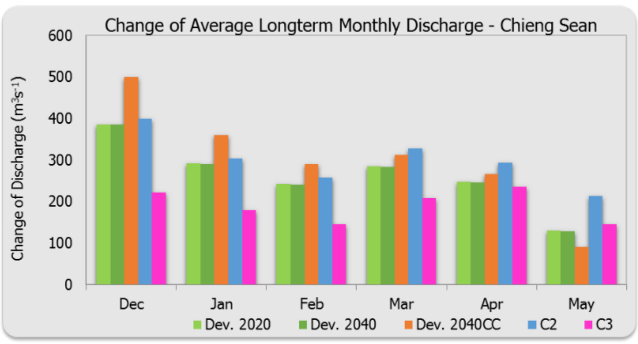


Figure 2 Monthly dry season flows at Key Stations Chiang Saen - Pakse (Average Monthly flow)

Figure 3 Dry Season Average Monthly Flow Key Station Kratie -Tan Chau

One way of analysing low flows is to plot the flow exceedance curve. This shows that at Chiang Saen the expected flow is above the baseline for dry flows for all Climate Change Scenarios. The drought conditions can thus be expected to have flows in the Mekong higher than the natural historic condition.

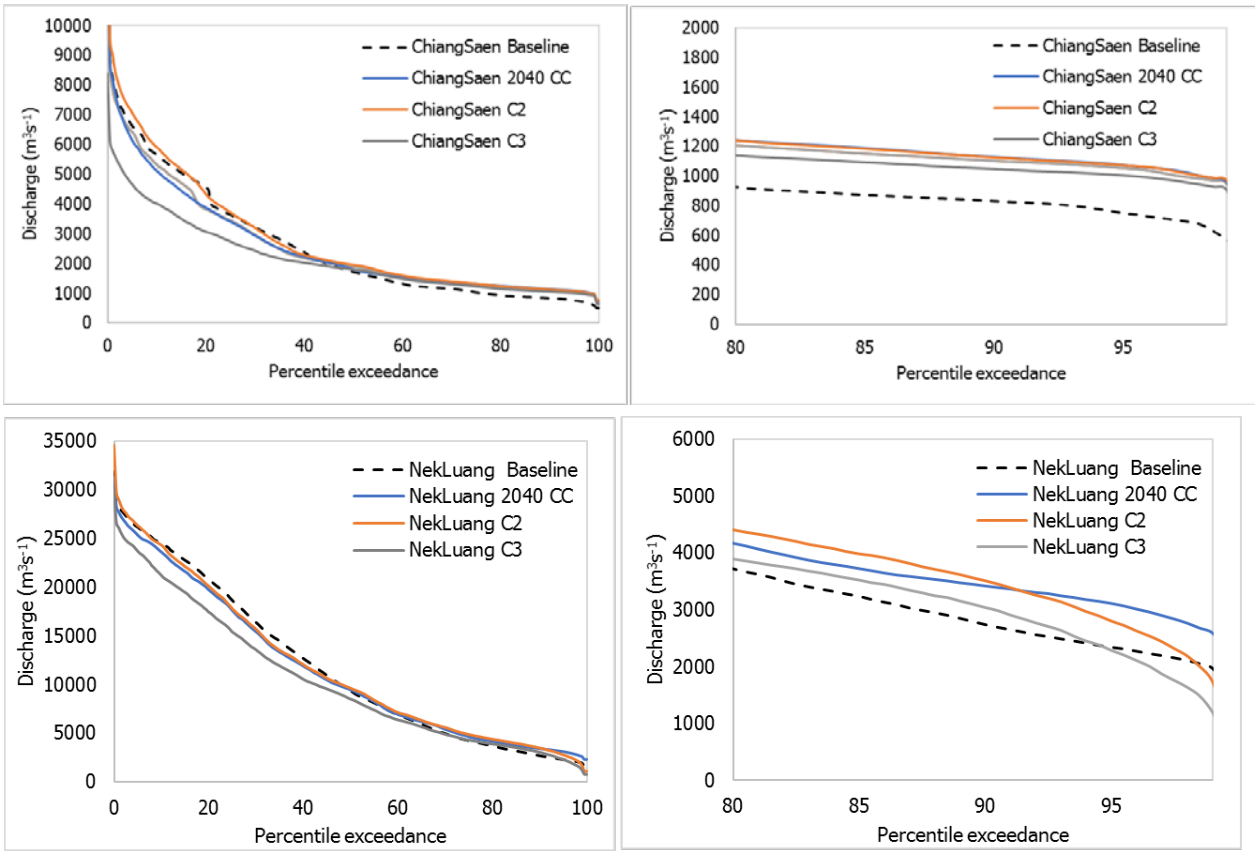


Figure 4 Flow Exceedance Curve for Mekong at Chiang Saen and Neak Luong

Similarly Q95 or the flow exceeded 95% of the time is often used as an indicator of low flows and calculation of change in low flows. As seen in the Table below, the variation in Q95 between Chiang Saen and Stung Treng is not high with all stations following a similar pattern.

Station	Q95 (m3s-1)					
	Baseline	Dev2020	Dev2040	Dev2040 C	C2 Projections	C3 Projections
ChiangSaen	750.2	1054.7	1054.1	1070.6	1069.7	1004.6
LuangPrabang	952.5	1304.0	1385.3	1443.9	1394.5	1266.2
ChiangKhan	1016.9	1366.9	1439.6	1482.8	1483.5	1327.2
VienTiane	1024.5	1353.5	1424.0	1467.5	1459.3	1301.6
NakhonPhanom	1377.6	1893.7	2006.6	2091.3	2043.4	1838.8
Mukdahan	1417.2	2027.6	2119.7	2172.6	2161.0	1946.1
Pakse	1409.6	2105.2	1997.6	2059.9	2061.1	1838.9
StungTreng	1866.4	2687.3	2123.5	2336.6	2670.6	2452.0

Station	Absolute change in Q95 (m3s-1)				
	Dev2020	Dev2040	Dev2040 C	C2 Projections	C3 Projections
ChiangSaen	304.5	303.9	320.4	319.5	254.4
LuangPrabang	351.5	432.8	491.4	442.0	313.7
ChiangKhan	350.0	422.7	465.9	466.6	310.3
VienTiane	329.0	399.5	443.0	434.8	277.1
NakhonPhanom	516.1	629.0	713.7	665.8	461.2
Mukdahan	610.4	702.5	755.4	743.8	528.9
Pakse	695.6	588.0	650.3	651.5	429.3
StungTreng	820.9	257.1	470.2	804.2	585.6

Station	% Change in Q95 (m3s-1)				
	Dev2020	Dev2040	Dev2040 C	C2 Projecti	C3 Projections
ChiangSaen	40.6	40.5	42.7	42.6	33.9
LuangPrabang	36.9	45.4	51.6	46.4	32.9
ChiangKhan	34.4	41.6	45.8	45.9	30.5
VienTiane	32.1	39.0	43.2	42.4	27.0
NakhonPhanom	37.5	45.7	51.8	48.3	33.5
Mukdahan	43.1	49.6	53.3	52.5	37.3
Pakse	49.3	41.7	46.1	46.2	30.5
StungTreng	44.0	13.8	25.2	43.1	31.4

Table 3-6 Q95 for flow at Key Stations Chiang Saen to Stung Treng for all climate scenarios

Further down the basin though analysis of the Q95 marker suggests that there will be times when flows are below M1 for example at Neak Luong downstream of Phnom Penh. This suggests that in more extreme droughts, despite the dry season increases of flow due to hydropower dam releases, there will be times when the flow downstream of Phnom Penh (including the Great Lake contribution) will be lower than base case M1.

The available time series was examined further for the dry year 1998 to look into the projected changes for different scenarios. As shown in the figures below most stations for most months remain above the M1 flow but this is not the case for December or May in many years and for the dry scenario there is even a lower flow at Tan Chau in the critical month of April. The analysis is still based on monthly averages so clearly there may be some days when flows fluctuate further depending on actual dam operations and releases including possible action that could be taken under the MRC PMFM procedures. Tan Chau shows a decrease in dry season flows for both C2 and C3.

TanChau	Dev. 2020	Dev. 2040	Dev. 2040CC	C2	C3
Dec	9.8	21.1	8.4	7.9	-6.4
Jan	13.2	25.9	14.0	24.8	9.1
Feb	15.5	26.7	17.5	23.7	6.8
Mar	31.6	48.4	30.6	20.7	-1.9
Apr	30.5	40.9	31.1	-15.5	-39.0
May	2.5	0.9	-0.3	-42.1	-47.0
Jun	-10.3	-26.8	-12.4	-21.5	-33.0
Jul	-15.2	-31.2	-22.7	-22.8	-34.0
Aug	-6.1	-18.6	-8.8	-9.6	-24.4
Sep	-4.9	-6.0	-6.1	-2.8	-14.7
Oct	-4.1	0.3	-4.7	-0.1	-12.3
Nov	-1.9	10.4	-3.6	2.5	-12.5
Wet season	-6.4	-9.8	-8.9	-7.1	-19.9
Dry Season	14.4	25.0	14.1	7.7	-7.7

Table 3-7 % Change Monthly Flows at Tan Chau simulated for an extreme dry year (1998)

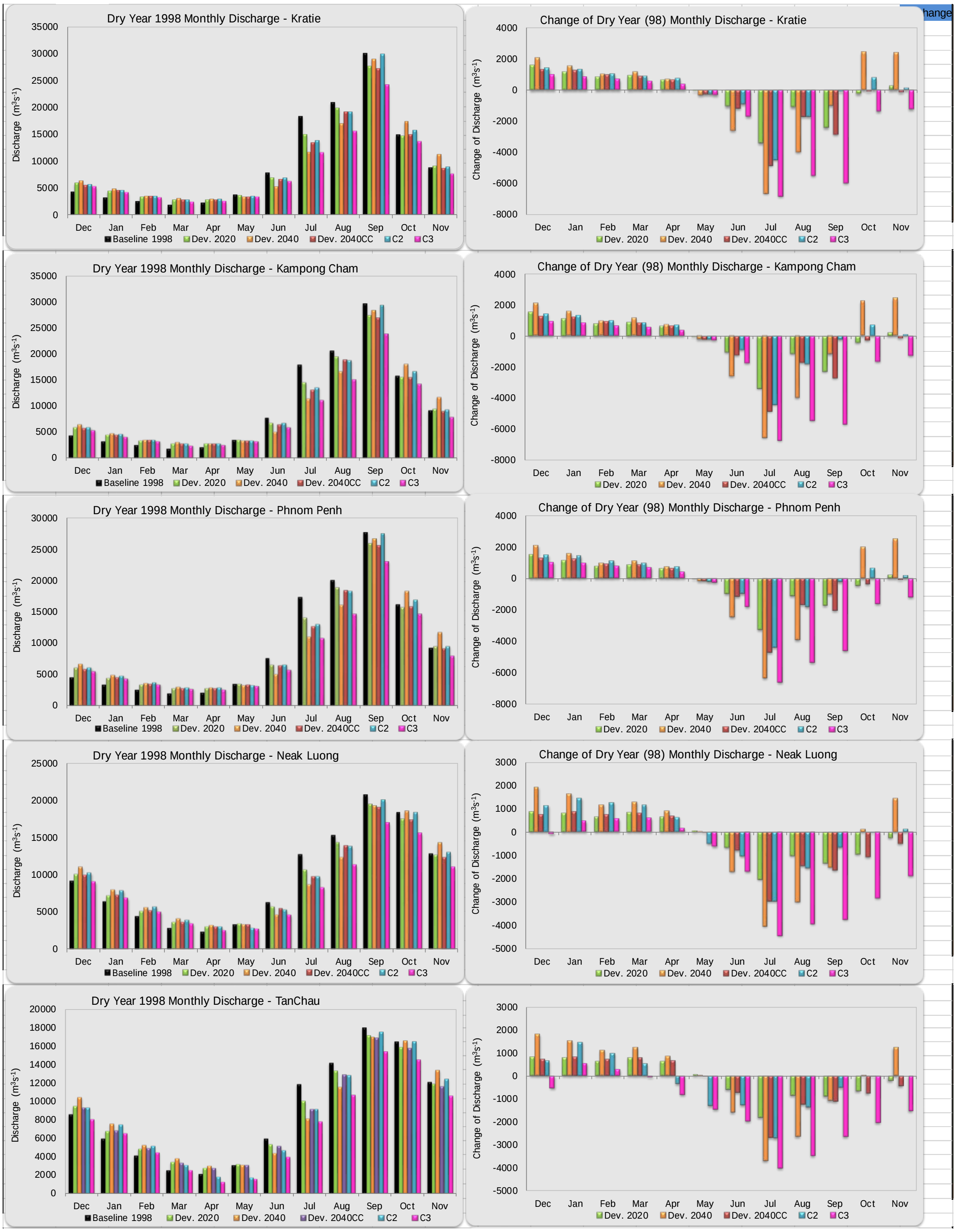


Table 3-8 Change in Flows at Key Stations for a dry year (1998) Kratie to Tan Chau

3.2.5 Effect of CC on Irrigation Water Demands

Irrigation water demand is modelled in the IQQM model from which results were abstracted and summarised. Irrigation demand depends on a number of variables including climate but also crop planting areas and patterns. There is a big change in expected irrigation demand between M1 and M3 which gives an overall increase of 41%. The additional change due to climate impact is relatively small compared to this as shown in the table below.

The wet season water demand is lower than the dry season due to the contribution of rainfall to the evaporative demands of the crop. The highest change calculated for the dry season is for the rice crop in Vietnam which shows an increase of nearly 28%. In reality this increase can be supplied when flows in the Mekong are high but difficulties can arise if the flood season is late starting as planting may be delayed and more prone to flood damage.

The difference in irrigation demands for dry season are dominated by the large demand in Vietnam though proportionately the highest increase was predicted for Lao in scenario C2 (wetter), a surprising result.

The overall annual change follows more closely the pattern that would be expected with overall change of 1.3% increase for M3CC (C1), 6.6% in the wetter scenario C2, but only 1.0% higher in the C3 scenario reflecting that in the drier scenario it may not be possible to supply sufficient irrigation water. In such cases the yields may be affected and salinity intrusion in the delta may increase.

	M3			M3CC			C2			C3		
	Wet	Dry	Annual	Wet	Dry	Annual	Wet	Dry	Annual	Wet	Dry	Annual
Cambodia	1692	2886	4578	1771	2921	4692	1857	2961	4818	1892	2839	4731
Laos	1348	3162	4510	1304	3348	4652	1594	3409	5003	1468	3025	4493
Thailand	4778	2802	7580	4268	2934	7202	5278	2957	8235	4802	2633	7435
Vietnam	2556	15366	17922	2568	15923	18491	2992	15830	18822	3270	14991	18261
Sum	10374	24216	**34590**	9911	25126	**35037**	11721	25157	**36878**	11432	23488	**34920**
		CHANGE	Cambodia	4.7%	1.2%	2.5%	9.8%	2.6%	5.2%	11.8%	-1.6%	3.3%
			Laos	-3.3%	5.9%	3.1%	18.2%	7.8%	10.9%	8.9%	-4.3%	-0.4%
Compared to M3			Thailand	-10.7%	4.7%	-5.0%	10.5%	5.5%	8.6%	0.5%	-6.0%	-1.9%
			Vietnam	0.5%	3.6%	3.2%	17.1%	3.0%	5.0%	27.9%	-2.4%	1.9%
				-4.5%	3.8%	1.3%	13.0%	3.9%	6.6%	10.2%	-3.0%	1.0%

Table 3-9 Change in irrigation water demand relative to M3 scenario in MCM (extracted from IQQM model, see Modelling Report Volume 5)

3.2.6 Effect of CC on Biological Resource

The results from the main scenario analysis of the BioRA team is shown in Table 3.6. The BioRA team consider certain focal areas and assess changes in these as representing the overall change in the nearby BioRA 'Zone'.

BioRA Zones and Focal Area	Assessment Zone (used in Socioeconomics)	Description	FA coordinates (longitude; latitude)
Bio Zone 1 (FA1)	Zone 2	Mekong River from the border with China to Pak Beng (confluence with Nam Beng)	19.8589; 101.0797
Bio Zone 2 (FA2)	Zone 2	Mekong River from downstream of the Nam Beng to upstream of Vientiane	18.2079; 102.1260
Bio Zone 3 (FA3)	Zone 3	Mekong River from Vientiane to Nam Kam town (near confluences with Xe Bang Fei and Nam Kam)	17.2066; 104.8061
Bio Zone 4 (FA4)	Zone 3/4	Mekong River from Nam Kam to Stung Treng (Se San / Se Kong confluences)	13.5559; 105.9511
Bio Zone 5 (FA5)	Zone 4	Mekong River from Stung Treng to Kampong Cham	12.2980; 105.5926
Bio Zone 6 (FA6)	Zone 5	Tonle Sap River at Prek Kdam, plus the Cambodian Floodplains excluding FA5 and FA7	11.87.87; 104.7827
Bio Zone 7 (FA7)	Zone 5	Tonle Sap Great Lake	12.8673; 104.0837[1]
Bio Zone 8 (FA8a, b, c)	Zone 6 & 7	The Vietnamese Delta from the Cambodian/Viet Nam border to the sea	10.6000; 105.4000[2]

Table 3-10 BioRA Focal Areas and Bio Zones

The results of the assessment show a significant difference between the base case M1 and the main scenario without climate change 2040 M3 no CC. Comparing the M3CC case with M3no CC it can be seen that the effects are limited, sometimes slightly less negative others slightly more in terms of the BioRA indicators.

The warmer, wetter conditions that lie behind the 2040CC scenario do not result in a significant improvement in river condition relative to the 2040 scenario because the major impacts are related to the decline in sediment supply, nutrients, and river connectivity associated with both the 2040 scenarios. The condition of the Delta is, however, expected to be slightly better under 2040CC than 2040.

[1] Marks centre point in Tonle Sap Great Lake

[2] Marks centre point in FA8a.

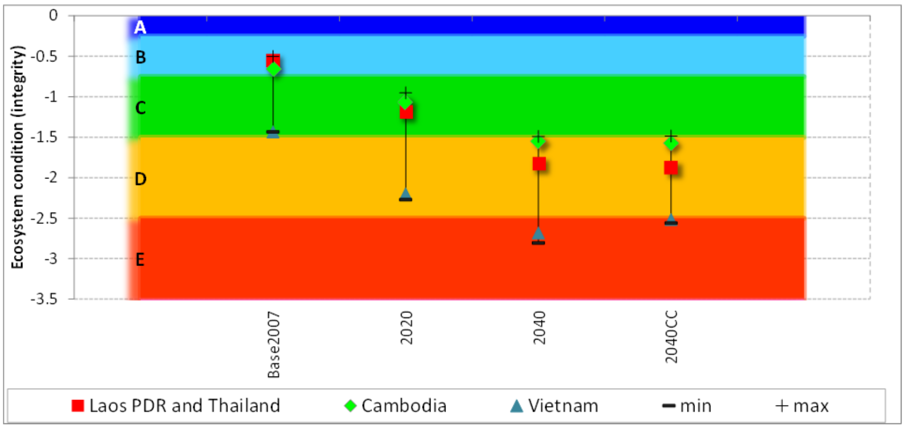


Figure 3.5 Ecosystem condition changes in main scenarios

The impact of climate change on the environment for the M3CC, C2 and C3 Scenarios is summarised in Figure 3.3.

There is very little positive with increased erosion and lower biodiversity expected particularly for the C3 Drier Scenario.

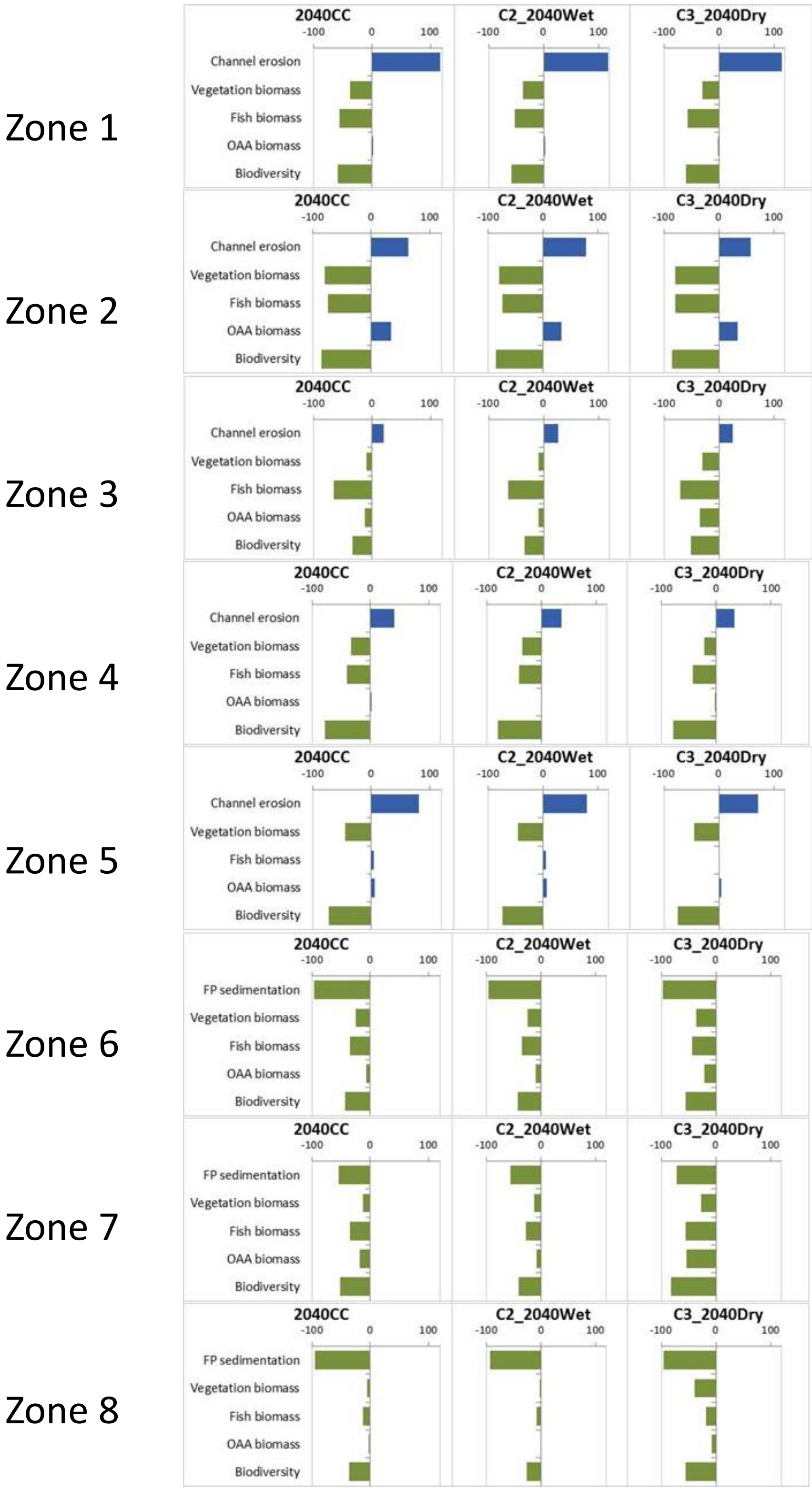


Figure 3.5 Summary of Climate Change Impact on the Environment by Bio Zone

CHANGE considered negative for ecosystem health		
<70%	40 to 70%	20 to 39%

Focus Area	Indicator		2020	2040	2040CC
FA 1	Erosion	river	+115	+115	+115
		impoundment	n/a	-100	-100
	Vegetation biomass		0	0	0
	Fish biomass		-25	-50	-50
	OAA biomass		+20	+20	+20
	Biodiversity		-20	-30	-30
FA 2	Erosion	river	+25	+25	+25
		impoundment	-100	-100	-100
	Vegetation biomass		-25	-80	-80
	Fish biomass		-30	-65	-65
	OAA biomass		+10	+35	+35
	Biodiversity		-40	-85	-85
FA 3	Erosion	river	10	15	10
		impoundment	n/a	n/a	n/a
	Vegetation biomass		-5	-5	0
	Fish biomass		-25	-50	-55
	OAA biomass		-10	-15	-20
	Biodiversity		-15	-35	-35
FA 4	Erosion	river	+35	+35	+40
		impoundment	n/a	-100	-100
	Vegetation biomass		0	-30	-35
	Fish biomass		-15	-40	-40
	OAA biomass		0	0	0
	Biodiversity		-25	-80	-80
FA 5	Erosion	river	+35	+55	+60
		impoundment	n/a	-100	-100
	Vegetation biomass		-10	-40	-40
	Fish biomass		-20	+10	+10
	OAA biomass		+10	+20	+20
	Biodiversity		-25	-65	-65
FA 6	Floodplain sedimentation		-65	-95	-95
	Vegetation biomass		-10	-15	-10
	Fish biomass		-15	-30	-30
	OAA biomass		-5	0	+5
	Biodiversity		-15	-35	-30
FA 7	Floodplain sedimentation		-25	-60	-55
	Vegetation biomass		-10	-15	-10
	Fish biomass		-15	-25	-35
	OAA biomass		-5	-5	-15
	Biodiversity		-20	-45	-45
FA 8	Floodplain sedimentation		-70	-95	-95
	Vegetation biomass		-5	-10	15
	Fish biomass		-25	-30	-30
	OAA biomass		-10	-15	-10
	Biodiversity		-30	-50	-40

Table 3-11 Biological Resource Assessment Results at Focal Areas for main scenarios

Impacts on Mammals

Zone	Indicator	Zone							
		1	2	3	4	5	6	7	
Scenario 2020	Irrawaddy dolphin				-45				
	Otters		-45		-20			-40	
	Wetland Mammals				-15				
Scenario 2040	Irrawaddy dolphin				-100				
	Otters		-60		-35			-65	
	Wetland Mammals				-20				
Scenario 2040CC	Irrawaddy dolphin				-95				
	Otters		-70		-40			-75	
	Wetland Mammals				-25				

Less than 2007				More than 2007		
<-70%	-40 to -70%	-20 to -39%	-19 to+19	+20 to +39%	+40 to +70%	>70

Table 3-12 Impact on Mammals

The difference between with and without climate change M3 scenario is varied but overidingly negative and generally made worse by climate change. A similar picture is seen for Birds and for wild fish as shown in Tables 3.8 and 3.9. An exception where climate change scenario helps mitigate is for estuarine dwelling fish which as shown in Table 3.9 for which a decline of -35 is mitigated to -25 for M3cc as compared with M3.

Zone	Indicator	Zone							
		1	2	3	4	5	6	7	8
Scenario 2020	Medium/large ground-nesting channel species	-10	5	-5	-15				
	Tree-nesting large waterbirds.				-40			-40	
	Bank / hole nesting species	0	0	0	-15	-20	-25	-20	-20
	Flocking non-aerial passerines of graminoid beds				0	-5	-15	-5	-5
	Large ground-nesting species on wetland floodplains							-10	-5
	Channel-using large species in bankside forest				-5			-10	
	Natural rocky crevice nester in channels		10	5	5				
	Dense woody vegetation / water interface				-20			-15	
	Small non-flocking birds of seasonally flooded vegetation	5	0		-15	5	0	-5	
Scenario 2040	Medium/large ground-nesting channel species	-10	5	0	-15				
	Tree-nesting large waterbirds.				-90			-65	
	Bank / hole nesting species	0	0	0	-25	-30	-45	-35	-50
	Flocking non-aerial passerines of graminoid beds				0	-5	-20	-5	-10
	Large ground-nesting species on wetland floodplains							-15	-5
	Channel-using large species in bankside forest				-5			-10	
	Natural rocky crevice nester in channels		15	5	5				
	Dense woody vegetation / water interface				-20			-15	
	Small non-flocking birds of seasonally flooded vegetation	5	5		-10	0	-5	-10	
Scenario 2040CC	Medium/large ground-nesting channel species	-10	10	-5	-15				
	Tree-nesting large waterbirds.				-90			-75	
	Bank / hole nesting species	0	0	0	-25	-30	-40	-45	-20
	Flocking non-aerial passerines of graminoid beds				-5	-5	-20	-5	-5
	Large ground-nesting species on wetland floodplains							-15	-10
	Channel-using large species in bankside forest				-10			-10	
	Natural rocky crevice nester in channels		15	0	5				
	Dense woody vegetation / water interface				-20			-15	
	Small non-flocking birds of seasonally flooded vegetation	5	0		-15	0	0	-10	

Table 3-13 Impact on Birds

Zone	Indicator	Zone							
		1	2	3	4	5	6	7	8
Scenario	Rhithron resident	-5	0	10	-5	-20			
2020	Main channel resident (long distance wh	-100	-90	-80	-65	-60	-50	-30	-60
	Main channel spawner (short distance w	-85	-45	-45	-25	-30	-30	-20	-55
	Floodplain spawner (grey)			-25	-20	-35	-40	-30	-50
	Floodplain resident (black)			-30	-40	-55	-40	-20	-45
	Eurytopic (generalist)	-15	5	15	-10	-25	-5	-5	0
	Estuarine resident						-30	-20	-20
	Anadromous			-45	-25	-15	-10	-5	-15
	Catadromous				-55	-15	-15	-15	-25
	Marine visitor								0
	Non-native	80	60	30	25	40	40	40	50
Scenario	Rhithron resident	-5	-5	25	-5	-35			
2040	Main channel resident (long distance wh	-100	-100	-100	-100	-100	-95	-90	-95
	Main channel spawner (short distance w	-100	-95	-80	-100	-95	-70	-65	-95
	Floodplain spawner (grey)			-15	-25	-45	-60	-60	-80
	Floodplain resident (black)			-15	-35	-70	-70	-40	-85
	Eurytopic (generalist)	5	40	50	30	-5	-10	10	10
	Estuarine resident						-55	-45	-35
	Anadromous			-100	-100	-55	-40	-20	-35
	Catadromous				-95	-35	-30	-20	-40
	Marine visitor								-5
	Non-native	115	110	80	85	90	80	80	95
Scenario	Rhithron resident	-5	-5	10	-10	-30			
2040CC	Main channel resident (long distance wh	-100	-100	-100	-100	-100	-90	-85	-85
	Main channel spawner (short distance w	-100	-100	-85	-100	-95	-65	-65	-80
	Floodplain spawner (grey)			-30	-25	-45	-55	-70	-40
	Floodplain resident (black)			-30	-35	-65	-65	-55	-35
	Eurytopic (generalist)	10	40	45	35	-5	-5	0	35
	Estuarine resident						-55	-55	-25
	Anadromous			-100	-100	-55	-30	-15	-15
	Catadromous				-95	-30	-25	-20	-20
	Marine visitor								5
	Non-native	115	115	95	80	85	75	70	70

Table 3-14 Impact on Fish by Zone

Zone	2020	2040	2040CC
1	-35	-55	-55
2	-40	-70	-75
3	-40	-60	-65
4	-15	-40	-40
5	-20	5	5
6	-20	-40	-35
7	-15	-25	-35
8	-15	-30	-10

Table 3-15 Overall Summary of % changes in Wild Fish BioMass by BioRa Zone for main scenario with and without climate change

In the Kratie river area, 2040 scenarios include M3CC and C2 climate change scenarios drop fish production from around 600kg.ha, to about 200 kg/ha. In scenario C3 fish production decreases to some extent in the upper section and increases in the lower section compared to the other 2040 scenarios.

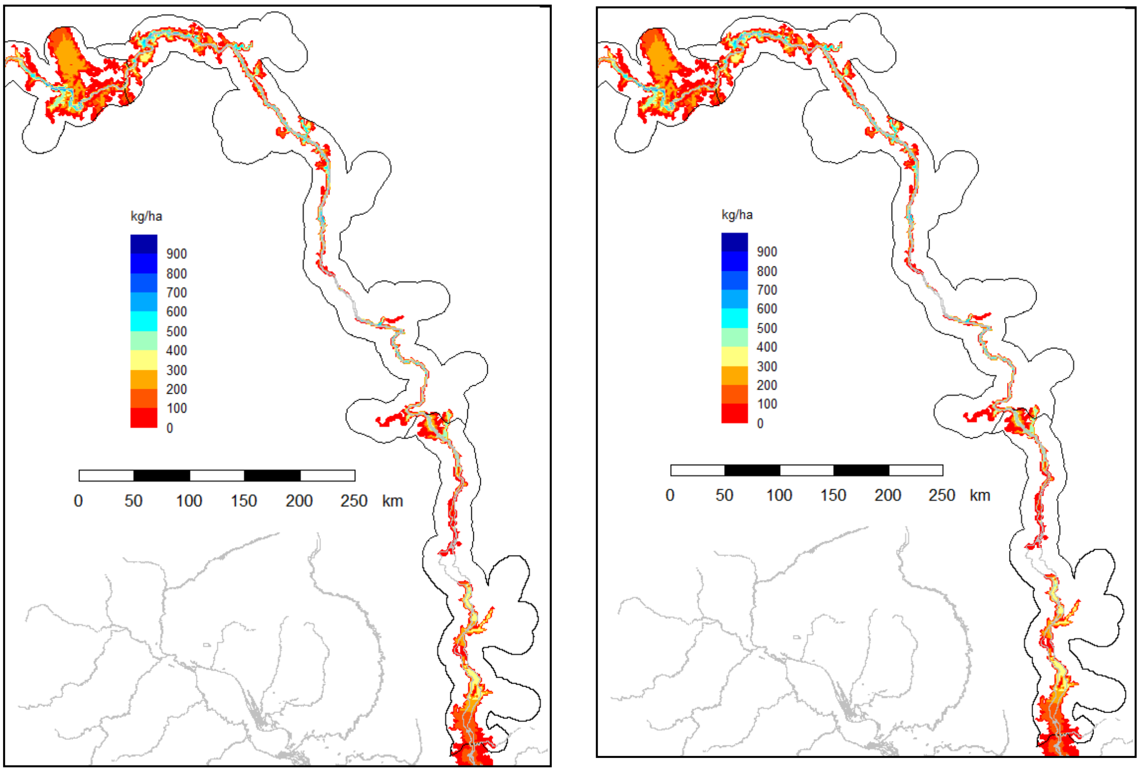


Figure 3.7. 2040 (left) and 2040M3CC (right) modelled fish production.

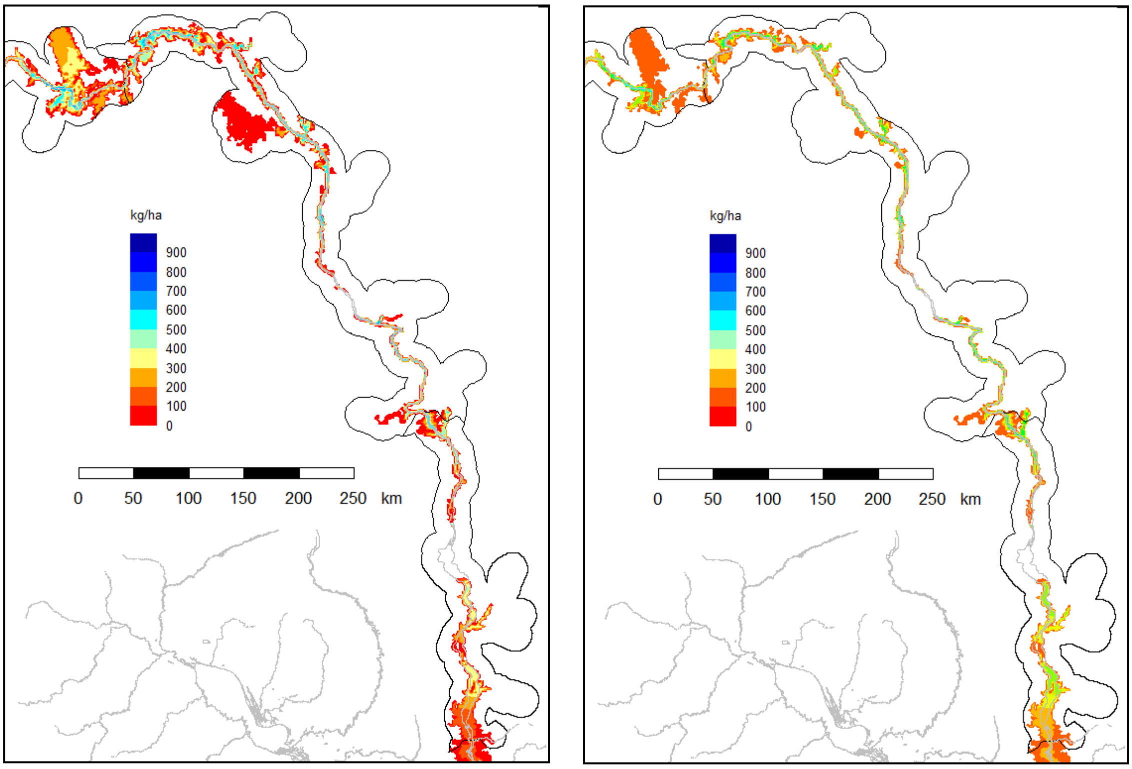


Figure 3.8. C2 (left) and C3 (right) modelled fish production.

The above details are available for the main scenarios but for fisheries as a whole clearly there are expected to be significant reductions in the availability of wild fish though climate change is not the principal driver of change.

3.3 Social Impacts

The Social Impact of scenarios of change have been carefully considered and reported on in the Socio economics study. There are impacts related to the Climate Change scenarios regarding:

- Food Security
- Employment
- Income
- GDP Changes
- Sector Contribution to GDP

These aspects as related to Climate Change show some significant change that differs spatially in the LMB.

Food Security for the most vulnerable groups is of concern as the countries transition into a higher standard of living overall and develop the water resources as planned. As shown in Table 3-11 the additional impact of Climate Change is significant in some locations and merely slightly deleterious in others. The dry scenario C3 has the most impact.

Effect of Climate Change on Food Security								
Zone	Food	M3	CC	C2	C3	CC	C2	C3
		Surplus Above Self Sufficiency (Average)				Change in Surplus		
Zone 4 C Cambodia Kratie to Viet Nam	Fish	34%	34%	34%	32%	0%	0%	-2%
	Rice	58%	63%	57%	57%	5%	-1%	-1%
Zone 5 A Cambodia-Tonle Sap river	Fish	5%	10%	14%	5%	5%	9%	0%
	Rice	45%	53%	47%	47%	8%	2%	2%
Zone 5 B Cambodia Tonle Sap lake	Fish	57%	53%	58%	32%	-4%	1%	-25%
	Rice	88%	89%	88%	88%	1%	0%	0%
Zone 2-Main – Lao PDR	Fish	-1%	9%	18%	8%	10%	19%	9%
	Rice	43%	38%	38%	36%	-5%	-5%	-7%
Zone 3-Main - Lao PDR	Fish	11%	14%	20%	12%	3%	9%	1%
	Rice	83%	83%	82%	82%	0%	-1%	-1%
Zone 2 B-Upper Thailand	Fish	43%	42%	44%	41%	-1%	1%	-2%
	Rice	86%	85%	85%	84%	-1%	-1%	-2%
Zone 2 C-Lower Thailand	Fish	84%	83%	83%	83%	-1%	-1%	-1%
	Rice	56%	54%	54%	50%	-2%	-2%	-6%
Zone 3 B Thailand-Mainstream	Fish	85%	84%	84%	84%	-1%	-1%	-1%
	Rice	64%	62%	62%	59%	-2%	-2%	-5%
Zone 3 C Thailand-Songkhram	Fish	84%	84%	84%	82%	0%	0%	-2%
	Rice	74%	72%	72%	69%	-2%	-2%	-5%
Zone 6 A VietNam Delta - freshwater	Fish	61%	63%	64%	62%	2%	3%	1%
	Rice	63%	64%	62%	63%	1%	-1%	0%
Zone 6 B VietNam Delta - saline	Fish	55%	62%	63%	60%	7%	8%	5%
	Rice	51%	52%	51%	51%	1%	0%	0%

Table 3-16 Effect of Climate Scenarios on Food Security by SIMVA Zone

During dry years the food security can become critical even if the requirements are met in an average year. Climate change has the impact of worsening the situation. The rice surplus of the LMB corridor may be summarised as changing:

	Rice	Fish
M1-M2	6%	-32%
M1-M3	16%	-43%
M1-M3CC	13%	-40%

Table 3-17 Overall Changes in Rice and Wild Fish for main Scenarios

This includes the planned expansion of irrigation and changing population so initially there is an overall improvement in the surplus of rice but this surplus is reduced by climate change. The Tonle Sap Lake Zone 5B is one of the most vulnerable. The number of undernourished people in Cambodia and Lao PDR increased in the M2 and M3 scenarios compared to the 2007 baseline, decreased in Thailand and remained relatively stable in the Viet Nam Delta. The social and economic assessment of the 1995-96 drought and 2000-2001 flood estimated a 10-11% decrease in rice production due to flood corresponds to 4.5-5% of the corridor population being affected; an 11% decrease in rice production due to drought corresponds to 3.1-3.3% % affected.

A drought similar in severity to the 1995-96 or 2015 El Niño or the 2000 flood coinciding with years of significant fish declines introduces the prospect of acute food shortages and reduced food security throughout the corridor, particularly Lao PDR and Cambodia. The analyses conducted by the CS BioRA and Modelling Teams indicate this is likely in at least four years of the 24 year projection horizon. More details are given in the socioeconomics report.

3.4 Economic Impacts

The most striking aspect of the macro economic aspect is that climate change is expected to impact negatively to quite a significant extent as shown in Table 3.12. The drier scenario C3 has the most impact.

	Cambodia	Lao PDR	Thailand	Vietnam	Total LMB
	Average	Average	Average	Average	Average
M1 Trend	48.3	39.2	79.8	82.3	249.6
M2	41.8	35.1	73.7	82.7	233.3
M3 (No CC)	39.6	30.2	68.9	82.5	221.2
M3CC	38.5	30.3	70.4	81.3	220.5
C2 (Wet)	36.3	30	69.6	78.9	214.8
C3 (Dry)	36.2	29.9	69.9	78.7	214.7
	GDP Projections for 2040 in constant 2017 Prices				
	Cambodia	Lao PDR	Thailand	Vietnam	Total LMB
	Average	Average	Average	Average	Average
M3CC	3%	0%	-2%	1%	0%
C2 (Wet)	8%	1%	-1%	4%	3%
C3 (Dry)	9%	1%	-1%	5%	3%
% Reduction in GDP Projections for 2040 Due to Climate Change					

Table 3-18 Impact of Climate Scenarios on GDP Growth

For Fisheries the change in Net Present Value under all different sub scenarios is shown in Table 3-13. It can be seen that after hydropower, the strongest influence is climate change and that fisheries are especially vulnerable to a drier climate.

% → M3CC	A1	A2	C2	C3	I1	I2	F1	F2	F3	H1a	H1b	H3
	no ALU	2020	Wet	Dry	no IRR	high IRR	no FPI	FPI	FPI	no HPP	no Main	HPP
Cambodia	0.1%	0.7%	3.3%	-14.6%	4.2%	1.3%	4.8%	4.4%	8.2%	27.5%	9.6%	9.6%
Lao PDR	0.5%	0.5%	0.7%	-7.9%	0.6%	0.5%	1.3%	0.0%	-0.3%	124.2%	63.9%	2.5%
Thailand	-0.2%	0.6%	0.6%	-7.2%	0.2%	0.5%	1.4%	0.0%	-0.3%	97.3%	46.2%	1.6%
Vietnam	0.3%	-2.6%	-0.9%	-4.4%	-1.5%	-2.2%	-2.2%	-4.4%	-3.7%	13.8%	7.0%	-0.2%
LMB	0.7%	-0.5%	1.4%	-9.7%	1.5%	-0.1%	1.7%	0.5%	2.4%	37.9%	16.9%	4.7%

Table 3-19 Effect of Climate Change on the NPV of Fisheries

The impact of Climate Change on the hydropower sector is shown in Table 3-14. Similar figures for climate sub scenario impacts on agriculture are not available.

Hydropower Sector NPV

$Billion NPV	Cambodia	Lao PDR	Thailand	Vietnam	Total LMB
M1	0	1.2	1	6.8	9
M2	8.8	19.6	30.7	15.5	74.6
M3 (No CC)	13.8	32.9	78.4	31.2	156.3
M3CC	13.8	35.1	80.3	31.2	160.4
C2 (Wet)	13.9	34.3	80.5	31.2	159.9
C3 (Dry)	13.6	32.9	77.4	30.9	154.8

NPV Projections for 2040 in constant 2017 Prices

	Cambodia	Lao PDR	Thailand	Vietnam	Total LMB
M3CC	0%	-7%	-2%	0%	-3%
C2 (Wet)	-1%	-4%	-3%	0%	-2%
C3 (Dry)	1%	0%	1%	1%	1%

% Reduction in NPV Projections for 2040 Due to Climate Change

Table 3-20 Effect of climate change on the NPV of the Hydropower Sector

4 Opportunities and Risks

4.1 Climate Change Impacts, Adaptation and Economic growth

The scenario analysis has revealed the likely extent of change and impacts due to the combined effects of development in the water sectors and climate change. The sub scenarios have shown the effect of a small range of climate change scenarios to 2040. This has provided a useful basis for the Council Study analysis although for climate change studies it must be recognised that the basis is quite limited. Further information for drawing conclusions can be drawn from other studies such as the MRC Basinwide studies of climate change that used 9 climate scenarios and climate projections for 2030, 2060 and 2090. Nevertheless impacts are seen in the Council Study Scenarios which usefully give more in depth information of the interactions between aspects and options for sector development and the changing climate than previous studies. The main risks identified in the Council Study for Climate Change Impacts are:

1. Changing extremes for flood resulting in higher peak flood levels and significantly increased flood damages during extreme events

2. Changing extremes of drought years resulting in lower flows and impacts on salinity and consequently agriculture including rainfed agriculture

3. Food security which is initially improved due to increased production and irrigation development is severely impacted in dry years resulting in potential food shortages in some locations

4. Loss of GDP growth potential and income from hydropower and agriculture

5. Impacts on the Environment including Fisheries especially for a drier scenario but also deteriorations in overall ecological assessment.

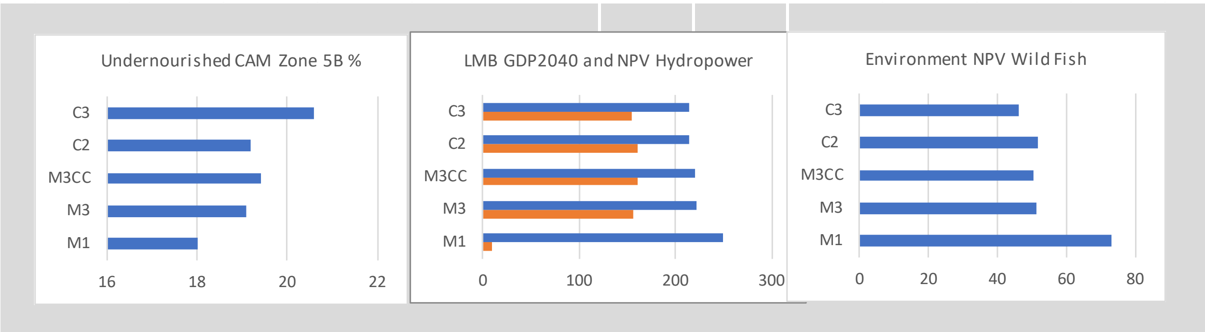


Figure 4.1 Impacts of climate change on three indicators. Comparison for main and climate sub scenarios.

The impacts are not even throughout the basin as shown in previous sections Cambodia is vulnerable for aspects of impacts especially flooding and fisheries, upper parts of Lao for Food Security and the Vietnam Delta for agricultural production and GDP growth.

4.2 Opportunities for Climate Adaptation to work to be mainstreamed into the planned developments in Water Resource Sectors – Agriculture and Irrigation

The development of agriculture including irrigation assumed in the Scenario formulation is that being planned in the LMB countries. The simulations show that these planned investments in agriculture have benefit to a degree and positive impacts on food security. The economic assessment finds that there is a loss in agricultural production or fisheries due to climate change. The production for 2040 with climate change though is still greater than the baseline for rice though wild fish If this loss is mitigated in the planned agricultural development then this demonstrates that such planning is a viable option for mitigating the losses due to climate change.

In the economic assessment the outright maximum development of agriculture is shown to be sub optimal given constraints of labour and water. Withdrawal of water for irrigation and protection against flooding also impacts on the environment and a balance between necessary agricultural development and minimising impact on the environment needs to be established. The Council Study has confirmed that adaptation to increase food production under climate change scenarios should be possible in an average year even if not for an extreme flood or drought. Improved seasonal storage and distribution of food may thus be needed in the adaptation.

4.3 Opportunities for Climate Adaptation to be mainstreamed into the planned developments in Water Resource Sectors –Flood Protection

Flood Protection provides an economic benefit not only to water sectors such as agriculture but will be increasingly important for other sectors by 2040.

The requirement for flood protection is linked not only to climate change considerations but also:

- Development of floodplains including urbanisation and Zoning for Maintaining room for rivers in extreme events and major road and rail developments
- Protection of agriculture to improve food security
- Disaster Risk Management
- Increasing Assets at Risk
- Society Attitudes towards flooding

- Changes in hydrology due to upstream developments in land use and dam development

- Bank protection and erosion dictating where defences may be sited

To adapt to increasing flood risk thus it is very clear that work for climate change should be linked to other and cannot be carried out in isolation. Climate change can however be an important driver and as shown in the example below the near doubling or trebling of flood damages can occur for different scenarios of climate change.

Corridor Vietnam Fresh water	Socio economic Development	Water Infrastructure	Annual Average Damage ($m)			AAD With Defences 10yr Rural 100 yr Urban	Damage Extreme Flood Event ($m)
	Year	Year	Agriculture	Other&Urban	Total	W/Defenses	1:100yr+
Scenario M1	2010	2007	5.4	24.8	30.2	2.6	155
Scenario M1	2040	2007	5.2	238.6	243.8	32.2	1,521
Scenario M3	2040	2040	3.5	160.6	164.1	24.6	1,171
Scenario M3 CC	2040	2040	9.5	373.2	382.7	68.1	3,187
Scenario C2	2040	2040	20.9	544.1	565.0	76.7	3,377
Scenario F2	2040	2040	9.5	63.4	72.9	Included	3,314

Figure 2 Example of Climate Change Impact for Vietnam Delta

4.4 Opportunity for the LMB to contribute to climate change mitigation

Greenhouse gas emission accounting and negotiations are conducted at the country level and are thus generally not considered by the MRC as a river basin organisation. The development of hydropower is supported internationally as a renewable energy source that is likely to decrease the emission of harmful greenhouse gases from conventional power plants. The LMB countries can thus benefit from reducing greenhouse gas emissions and the financing that supports it (eg the Clean Development Mechanism).

Such benefits should help in offsetting negative impacts on fisheries or erosion for example whether these occur locally or in a transboundary context.

5 Implications for Planning and Policy

5.1 Development planning for water resources development in the Lower Mekong Basin should include a realistic range of climate scenarios and should be linked with adaption planning

The findings of the Council Study provide a good example of how closely linked sectors should be analysed and not treated in isolation.

In particular the social aspects of change, the economics and the wider macroeconomics must be more closely linked with the decision making. Effects on the environment may be significant and more advanced techniques of hydrological modelling including sediments and water quality are needed for the Mekong.

Because the future changes expected in the basin are so multi-faceted and dependent on multiple sectors, not only those water sectors considered by the MRC, some better framework for assessment of projects is needed so that the overall objective of development for improvement of the society can be realised. The Council Study has shown the direction and a possible path.

Climate Change is an important facet of expected change but one that is expected to be relatively slow change with a high degree of uncertainty for the water sector which is very dependent on projections of changes in rainfall and sea level rise. Adaptation plans for future climate that do not consider the whole environment of development and change should be of concern as they will have a high risk of becoming redundant, or solving last years problems and result in wasted expenditures.

Much more productive is likely to be integration of climate change into development planning, for example adding allowances to the height of new roads or urban development rather than increasing levels later. In the Lower Mekong though there is still a lack of realistic macro level planning for climate change especially where there are basin or transboundary issues.

5.2 Increased cooperation in planning of water resource development is needed as the transboundary impacts are significant

The Council Study demonstrates that much of the water resource development in the Mekong Basin (including the Upper Basin) has transboundary impacts elsewhere. These impacts may be positive or negative.

Examples are:

- Dry season Flows in Drought Conditions influenced by dam operations

- Sediment Trapping in Dams causing bank erosion downstream
- Flood protection upstream causing increased flood risk downstream
- Climate Change impacts from heavier local rainfall, typhoons and sea level rise.
- Climate Change impacts from other meteorological changes such as temperature affecting crop yields, affecting crop water demands, affecting water quality, power demands thus affecting decisions on dam operation at critical times,
- Climate pressures on ecosystems including fire and changing ecosystem zones.

Each impact together can build up a significant cumulative impact so a more integrated basin wide approach for planning is highly desirable.

6 Knowledge Gaps

6.1 Knowledge of Possible future climate extremes needs strengthening

The study has highlighted some very important aspects of the potential change in effect of climate extremes both for flood and for drought condition.

The flood extremes predicted with climate change are potentially for a high change and for this to impact more strongly due to the increased assets at risk. A single high return period event could then have a high level of damage. The knowledge of changing flow with climate is thus an important topic to continue to improve knowledge.

Drought effects have hitherto been thought to have been largely compensated by the increased average flows from hydropower releases. The council study analysis has identified howebver that in extreme drought years these releases are insufficient to even match the baseline flow condition at the lower part of the basin. The effect of this on salinity intrusion, crops yields and economic impact need significantly more study.

6.2 Understanding of the social impacts of water resource Impact of climate change is improving but still insufficient for detailed cumulative impact assessment

The social impact assessment has shown some key concerns for food security, income etc. The linkage between hydrological analysis and climate with social impact can be significantly improved with better integrated studies and data.

6.3 The ecological impacts of climate change

The ecological changes predicted with climate change have focussed on the change in conditions within the river environment only. That assessment is still largely based on broad indicators and simple response functions that depend on a better understanding of likely changes in habitat and species response. The utility of the available assessment and the knowledge gaps are clear to see especially as regards to the key aspect of the fisheries response to multiple changes.

The changing ecology of the basin as a whole due to meteological changes of temperature and precipitation is predicted under the MASAP studies but is not yet included in the expected Land Use change scenarios so should be in the future. The change in flooded forest, for example may be linked with changing temperature as well as hydrological changes.

More detailed study of the changing ecology of the river system should take account of the changing water quality and simulation of the natural river lengths and the changing ecology in impounded reaches behind mainstream dams is needed to link with the ecological assessment.

6.4 Hydrological Modelling of Climate Change

The approach used for modelling of hydrology and river hydraulics using DSF and WUPFIN tools has successfully produced results for the Council Study. But enhancement of these techniques is really needed to improve the knowledge and assessment especially related to:

- Extreme event analysis – the time series used for long term simulations must be extended
- Water Quality Modelling – the simulation of salinity intrusion depends on the correct setting of tidal boundaries for salinity. Further study of the changing salinity at the mouths of the Mekong for different scenarios are needed.
- The simulation of water quality and movement of Nitrogen and Phosphorus is at an early stage and more detailed study of the basinwide movement and interaction with sediments and bed/algae is needed. The settling processes with dams and likelihood of algal blooms remains a clear knowledge gap.

The Council Study considers changes up to 2040 only and thus there is little difference between the various emission scenarios of the IPCC and a central one was selected for study only. The differences between this central scenario and other emission scenarios gets larger as time progresses and thus to look further in the future more scenarios should be considered.

6.5 Sediment Modelling

The available tools at MRC for sediment modelling have been used but the time for a detailed study has been very short given the magnitude and complexity of the task. The data available on key aspects is also very weak, for example the sediment grainsize of sediment in transport has very few measurements. The behaviour of sediment for different operation of dams needs a more detailed study linking better with existing models and the downstream impacts including prediction of erosion and rates of change under different scenarios.

6.6 Impact Modelling

The modelling of the impact of a changing hydrology and climate has been attempted using WUPFIN tools for flooplain sedimentation, agricultural production, coastal erosion and fisheries production. There is uncertainty in the prediction that though not a knowledge gap, needs more analysis and calibration to ensure trends are being correctly simulated. The fertilising effect of a rising CO2 level under climate change that is assumed for example is uncertain and if it does not occur in practise the loss of crops yield may be significant.

6.7 Effect of Hydropower Dams on Green House Gas Emissions

To date MRC has not collected nor analysed any information on Green House Gas emissions when impounding reservoirs and the CO2 emissions reduced through hydropower generation. This would seem to be a gap in knowledge that is important for informing decisions on development in the basin and is key for climate funding.

7 Recommendations and Conclusions

7.1 Key Findings

The Climate Change simulations linked with the extensive impact analysis of the Council Study have revealed aspects not detailed before including:

Hydrological and Climatic Impact

Three climate scenarios to 2040 have been tested in the study. Each scenario has similar increases in temperatures but differing changes in rainfall which is where the main uncertainty for climate change prediction lies relating to water resources. The three scenarios tested are designed to cover the possible range of likely change assuming a medium level of greenhouse gas emissions (RCP4.5). The expected sea level rise is also included and is similar for each climate scenario.

The changes in mean flows are dominated by the changing water infrastructure in the study scenarios but variability between years such as in a peak flood are strongly influenced by climate change.

Social Impact

Various aspects of social impact are apparent including the number of people affected by flood or drought. However, the indicator that best summarises the impact is food security, which takes account of the differing response of crops and fisheries to changes in the river regime. Food surplus approximates the capacity to manage and adapt to acute food shortages. Increased surpluses correspond with increased capacity. The changes from climate change are generally negative with the impact on fish in the Tonle Sap lake for the dry scenario having the most deleterious impact. The crop modelling assumed a positive impact of increased atmospheric CO_2. Translation to field conditions remains uncertain however.

In general food sufficiency is adequate in an average year, but in a critically dry year any significant reduction with climate change could cause significant problems for the poorest households and an additional strategy to alleviate this will be needed.

Economic Impact

The macroeconomic study considers the effect of different scenarios on a range of issues such as overall GDP, employment and the impact of different sectors. the most striking finding of the climate change scenarios is that there is a significant reduction in the future GDP for all scenarios, particularly for Cambodia and particularly if the drier scenario should materialise. Such impacts could seriously damage the prospects of Cambodia sustaining lower middle-income status.

7.2 Climate Change Impacts must be included in planning

The magnitude of change expected with climate change is significant and can seriously influence the success of development.

7.3 Climate Change Scenarios covering the likely range of climate change are needed and must include sea level rise where appropriate

Three climate scenarios derived from IPCC simulations have been used to represent the three main possibilities affecting water resources (ie based on precipitation change):

1. Seasonal Change (chosen for the main scenario M3CC as the most likely change) with little overall basinwide average change in yearly precipitation total but wetter wet season with slightly later timing and drier dry season extremes.

2. Wetter Climate (in wet and dry season)

3. Drier Climate (in wet and dry season)

7.4 Use a comprehensive integrated System for Planning and Assessment

The Council Study has used 3 Climate Scenarios within a comprehensive integrated framework of 10 modelling techniques for simulation and assessment:

1. Hydrological Modelling (SWAT, IQQM, Source)

2. Hydraulic Modelling (ISIS/Flood Modeller)

3. Sediment Modelling (SWAT, Source ISIS/Flood Modeller, WUPFIN tools)

4. Water Quality – salinity, Total Nitrogen, Total Phosphorus (SWAT, Source ISIS/Flood Modeller, WUPFIN tools)

5. Agriculture Yield (WUPFIN Tools)

6. Fisheries simulation (WUPFIN Tools and BioRA/Drift)

7. Biological Resources Indicator Model (WUPFIN Tools and BioRA/Drift)

8. Socioeconomic Assessment

9. Food Security

10. Macro economics

The system used comes from a number of disciplines and uses data from member countries.

Whilst successfully showing the key impacts of Climate Change coupled with development the system could be significantly improved and it is recommended that the Council Study methodologies are strengthened and capacity is built in the use of such tools that could be shared between MRC and line agencies to allow a complete analysis of proposed development paths and individual projects.

It is also recommended that climate change adaptation measures are included in future work and the interdependence of development, climate change are studied to a more distant time horizon like 2060 or 2100 and the prediction of the range of likely precipitation changes is urgently updated to reduce the relatively high uncertainty now apparent in climate projections available.