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

Flood Sector Key Findings Report

Flood Protection Structures and Floodplain Infrastructure

(Unedited Version 3.1)

Prepared by: The Council Study Core Team

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Disclaimer

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Document history

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Executive summary Flood Protection and Floodplain Development

Introduction

Flooding within the Mekong basin is a frequently occurring natural process that brings benefits (such as fish and deposition of nutritious sediment on agricultural lands) as well as negative impacts of flood damage during extreme events. The traditional way of managing floods in the Mekong until present has been to develop high resilience and adaptability to 'Live with Floods'. Looking to the future though, the combined impacts of climate change and changing society and infrastructure are increasing the requirements to protect people and assets whilst managing development by multiple sectors. The Mekong is a major transboundary river that has a complex hydrological regime driven by yearly rainfall events from different parts of the catchment. Importantly, the local floodplains play an important role in attenuating the resultant flood waters as they are conveyed downstream. Changes in upstream characteristics can lead to downstream impacts and progressive loss of floodplain throughout the basin will cause higher extreme floods.

This sectoral assessment for the Council Study fits in with other sectors in looking at the impacts of multiple change, the needs for adaptation within the sector and the likely impact of those changes elsewhere. The triple bottom line framework involving integrated economic, social and environmental impact assessments is used to undertake the assessment.

The sectoral assessment follows the principles of best practice flood risk management (integrated flood risk management IFRM) as set out by the MRC FMMP studies 2006-2010 (MRC/Haskoning 2010) and continued in more detail under the 'Initial Studies' (FMMP2015). These latter studies further investigate detailed planning and floodplain development issues with Member Countries. In each case a probabilistic approach to flood analysis is used recognising that extreme events will occur with a certain frequency and any mitigation measures (hard or soft) or impact analysis must take this into account.

Assessment Outcomes:

The integrated approach of the Council Study has brought a sharp focus on the four main flood issues of:

1. Flood Damages will rise rapidly by a factor of 5-10 with development unless protection is provided;

2. The trapping of sediments in the proposed dams in the Mekong Basin will increase River Erosion in the LMB and significant bank protection work will be needed;

3. If uncontrolled, the loss of Floodplain storage with development will result in higher river flood levels and increase flood levels and frequency or river and surface water flooding;

4. Climate Change is highly likely to result in significant increases in floods especially in the upper part of the basin and the in the Mekong delta.

Consultation with MRC Member countries revealed a lack of longer term strategic planning for improving flood protection works in the Council Study assessment corridor. Analysis indicates that without further protection flood risk and potential damage will increase 5 to 10 times relative to 2008 baseline by 2040. This is primarily due to the expected rise in the value of assets at risk as the economies develop, especially in urban areas with higher exposure but is also influenced by climate change and development on floodplains.

Development of storage dams has the effect of slightly reducing the more frequently occurring floods but has little impact on extreme flood events. Climate Change could impact flood peaks significantly and will reverse the mildly positive effect of dams on floods and will likely result in high increases in flood severity especially in the upper part of the LMB.

Reductions in sediment load due to upper basin, lower basin and tributary dams will necessitate significant expenditure on bank protection in Cambodia and Vietnam's Mekong delta. Transboundary erosion will increase rapidly with the completion of dams in the lower Mekong basin. At risk river bank protection will require investments of up to $6 billion. If erosion protection is required then advantage may be taken to improve the flood protection level at a lower additional cost.

Recommendations

The approach of the Council Study is unique in the way that water resources and external development impacts in the river basin have been considered as a whole in an integrated fashion rather than taking a narrow sectoral basis as in many planning and project studies. The analysis has also gone further than earlier MRC basin planning to integrate models and predictive tools for economics and social impact and though incomplete it is suggested that the work is progressively improved and the lessons learnt are made widely available to member countries for future planning.

The areas that stand out as deserving further priority attention relative to flooding are:

1. Better information must be collected on the current flood defences, bank protection and damages and made available in a more useable form

2. The prediction of the change in future Flood Damages with development must receive more attention and improved methodologies made available.

3. Floodplain management guidelines utilizing flood zone mapping are needed in each country and wider sharing of data for transboundary areas

5. Further study is needed to reduce the uncertainty on trapping of sediments in the proposed dams and the effectiveness of possible mitigation measures. This could also include nutrient cycle analysis and potential for harmful algal blooms.

6. Further study is needed on the impact of the reduction of sediment on bed and bank erosion, coastal erosion and river morphology and a costed sediment management plan developed for erosion protection measures to be taken for the whole LMB over the next 20 years. This plan should include the management of sediment for navigation dredging,

the need for building materials and land raising that goes with development as well as sand mining for construction and land raising.

7. Modelling of the interactions between flooding, sediment movement, nutrient and agriculture development needs to be continued and improved with linkage to planned irrigation schemes and the effect on the biological resource and environment.

8. Pilot Studies of Flood Protection works should be undertaken to a level that demonstrates the economic feasibility of flood defence improvement and to establish guidelines for the economic and social standards of protection that should be aimed for in rural and urban areas.

9. Planning of Climate Change adaptation for floods must be closely linked to the changes in situation due to development.

10. Longer Term Strategic Planning for flood Protection and River Bank protection should be incorporated in the next MRC Basin Plan or a specific basinwide flood sector plan.

11. Hydrometric data improvements in terms of better quality of data and longer timeseries for simulation are strongly needed to support the planning.

12. Improvements in the MRC modelling and assessment system that can provide transparent and more robust outputs and decision support should be made. It is important to continue to improve the basic data, the core DSF models, incorporate the social, biological resource and economic impact tools into a more streamlined system and further develop tools for agriculture simulation, flood damage assessment etc.

13. The MRC Flood team's 'Initial Studies' should be advanced rapidly to define in better detail the impact of likely floodplain developments and the possible solutions. This should lead onto the first draft of a strategy for management of the floodplains of Cambodia and the Mekong delta as identified in the MRC Strategic planning in 2010. The plan should link closely to the planning of member countries and address the opportunities and constraints of the transboundary impacts identified.

14. The methodology for calculation of flood damage where there is rapid development should be advanced and improved and capacity built in the use of the tools and techniques through 'bottom up' approaches using unit calculations for housing, industry, infrastructure and agriculture that are more adaptable than the rigid bottom down approach that inevitably assumes a similar condition to the present.

15. Further to flood damage estimates the economic value of flood benefits is also required.

16. The MRC DSF tools and datasets should be updated to incorporate fully the assessments required in studies such as the Council Study and made available to a wider audience to ensure better accountability and transparency.

Contents

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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)
CIA	:	Cumulative Impact Assessment
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

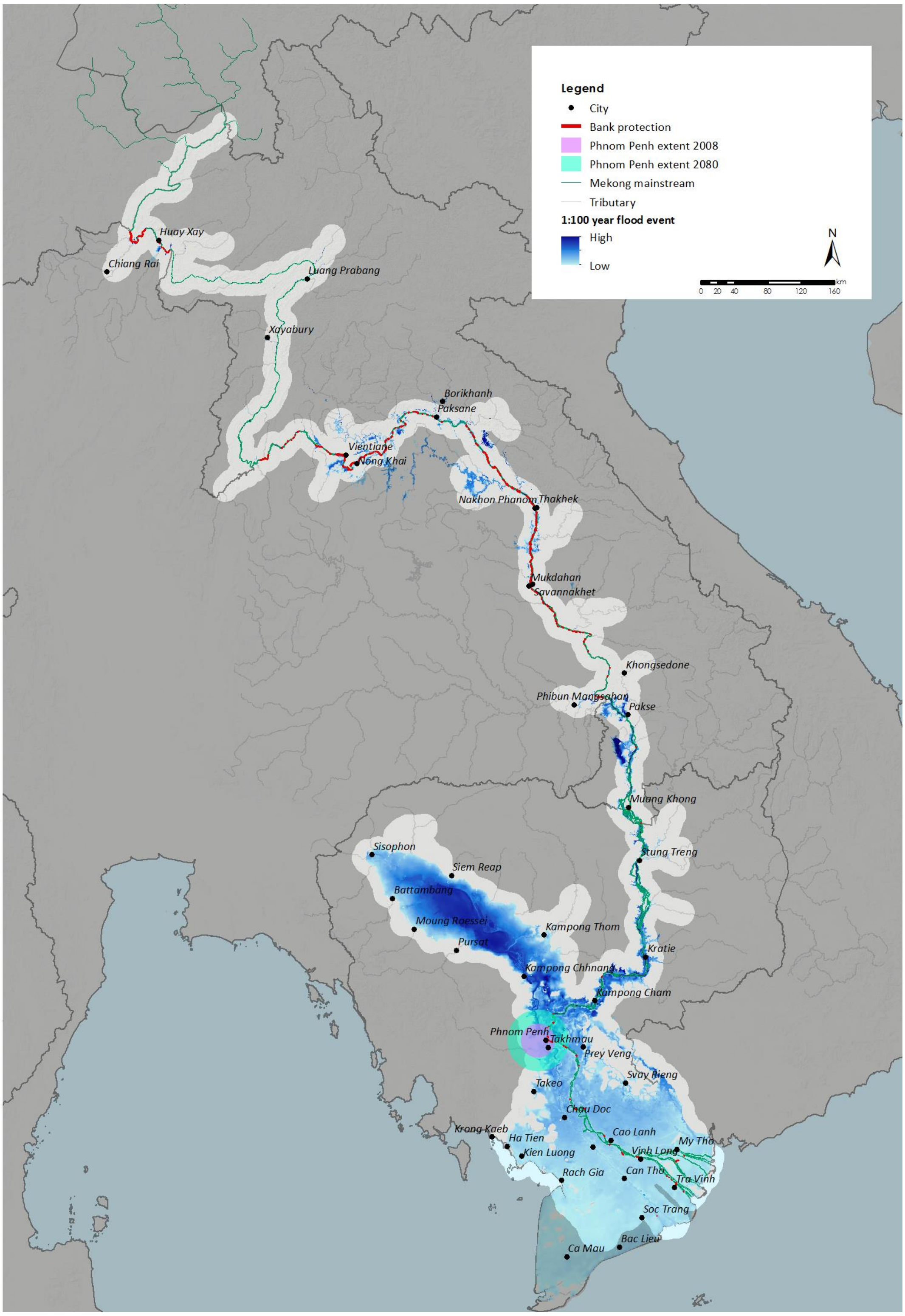


Figure 1-1 The Council Study Impact Corridor used in this study and the estimated 1:100 year flood extent

1 Introduction

1.1 Purpose of this report

The purpose of this report is to present the key findings of the Flood Thematic aspects of the MRC Council Study (Theme 4 of the Council Study **Flood Protection Structures and Floodplain Infrastructure**). The assessment integrates the findings of the social, economic and environmental assessments to identify the key impacts and benefits of selected water resources developments.

The agreed scope of the report as set out in the Council Study Inception Report (MRC 2014) is *'To provide an assessment of the transboundary flood protection benefit and risks of existing and planned infrastructure. Furthermore, it will describe how these structures can influence river flow in terms of quantity, quality, timing and content and the resulting transboundary positive and negative impacts on environmental, social and economic parameters. The change in sediment transport and ecosystem fragmentation will be a key section in the report as they are highly relevant for agriculture and fisheries, thus for food security.'*

Recommendations are made on measures and strategies to avoid or mitigate the most significant negative impacts of flood protection structures and floodplain infrastructure, including roads and urban encroachment onto major floodplains.

The findings of the Council Study assessment are presented in three strands: Firstly, in terms of impacts on people (social), the economy (economic) and the environment. Secondly according to thematic areas (this report) and thirdly in terms of trade-offs, synergies and other forms of interaction. In all cases, every 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 the Flood Sector and the adopted assessment indicator framework. The main body of the report presents the findings with further details on status and background information provided in the 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 (This Report)
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)

1.3 Introduction to the Council Study

During the Third Mekong-Japan Summit in Bali in November 2011, Prime Ministers of the four MRC Member Countries resolved to conduct a Study on Sustainable Management and Development of the Mekong River including Impacts of Mainstream Hydropower Projects. The MRC Council commissioned the study at its 18th meeting in Siem Reap in December 2011. The Council Study, as it became known, aimed to provide an objective scientific assessment of the environmental, social and economic costs and benefits of existing and planned water resource developments in the Lower Mekong Basin to inform decision makers.

The Council Study used a sequence of qualitative and quantitative models to examine a set of water resource development scenarios. The modelling outputs were integrated as a systematic framework to describe outcomes for selected environmental, social and economic indicators and to carry out assessments. These, in turn, informed the social and economic analysis of six thematic sectors. The framework provides a coherent, scientific foundation for the assessment of water resource developments and is complemented with accessible, practical methodologies and modelling tools, and a knowledge base to support further studies, deliberations and decision processes.

The Council Study examined three main water resource development scenarios: (i) **The *early development scenario*** characterizing baseline water resource developments in 2007 (M1); (ii) **The medium-term *definite future scenario*** characterizing existing, under-construction, and firmly-committed water related developments in 2020, including the Xayaburi and Don Sahong hydropower projects (M2); and (iii) **The long-term *planned development scenario***, characterizing the planned water developments in 2040 in addition to those assigned for 2020 (M3) for implementation over the following two decades. The main scenarios aggregate combinations of water resource developments enabling the cumulative assessment of environmental, social and economic effects in the Member Countries.

Assessing the cumulative effects of a combination of investments tends to mask the consequences associated with individual developments and/or thematic areas. Twelve sub-scenarios were evaluated to isolate sector-specific contributions and comprise reductions or increases in sector-specific investments relative to those in the M3 scenario of agricultural land use, flood protection infrastructure, hydropower and irrigation. A set of three sub-scenarios was also devoted to isolating the impacts of Climate Change.

The study was designed to be flexible, transparent and repeatable to accommodate improved data management and continued refinements of the assessment tools. The importance of the study assessment framework is not that it is definitive and without information gaps, but that it provides a robust science foundation combined with an accessible, practical methodology and knowledge base to support further studies, deliberations and decision processes.

2 Design of the assessment

The assessment follows the principles of IWRM and IFRM that adopt a probabilistic approach to the analysis of floods. The Council Study has available continuous simulation modelling that covers a period of 26 years which is just sufficient for flood frequency assessment up to 50 years average recurrence interval.

2.1 Process

The impact assessment for the flood sector fits with the overall Council Study Cumulative Assessment and discipline team outputs as shown in Figure 2.1.

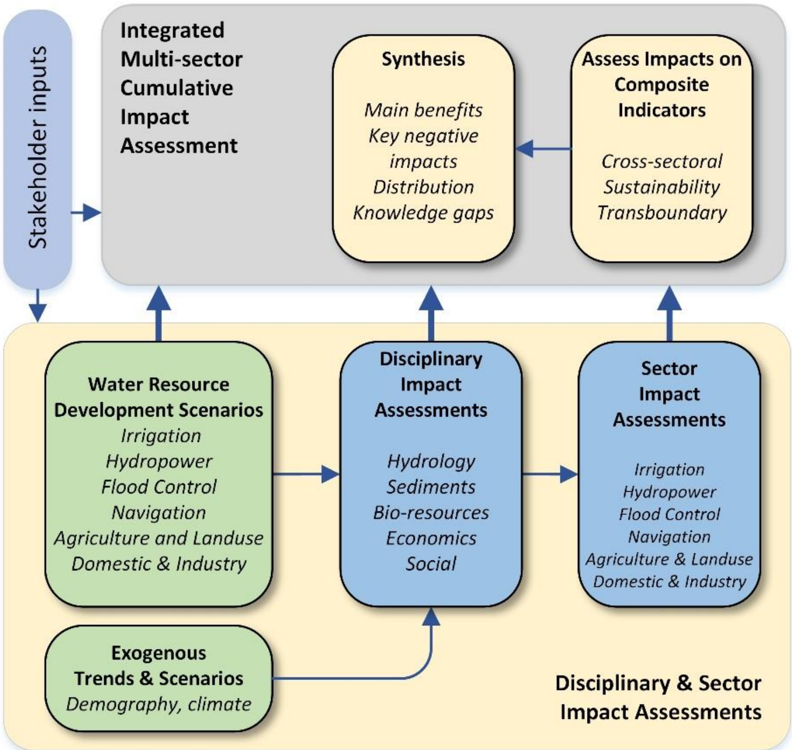


Figure 2-1 Sector Analysis of the Council Study

2.2 Development Scenarios for Flood Protection and Floodplain Development

2.2.1 Formulation of 'Main Scenarios"

The SWAT, IQQM and ISIS models reflecting 2007 development conditions are available with IKMP and were used as a basis for simulation runs. These models have been checked and modified as necessary to incorporate more recent modelling improvements, for example improvement in channel representation. These improvements, however, are not related to infrastructure or floodplain development. The reference scenario M1 'Early Development' uses this condition.

2020 M2 and 2040 M3 Development Scenarios

The SWAT, IQQM and ISIS models were updated to include land use change, irrigation and dam developments that have already occurred and are planned to be implemented by 2020. The modelling team did not include changes in the lower model for floodplain development and this is instead included in a sub scenario.

A summary of key aspects of the three development scenarios is provided in Table 2.3.

	Scenario	Level of Development for water-related sectors*						Climate
		ALU	DIW	FPF	HPP	IRR	NAV	
M1	Early Development Scenario 2007	2007	2007	2007	2007	2007	2007	Historic Climate
M2	Definite Future Scenario 2020	2020	2020	2020	2020	2020	2020	Historic Climate
M3	Planned Development Scenario 2040	2040	2040	2040	2040	2040	2040	Historic Climate
M3CC	Planned Development Scenario 2040 Under Climate Change	2040	2040	2040	2040	2040	2040	Seasonal Change for 2040 Climate
M1960	1960 Development*							

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

*1960 – Historic Development Scenario not implemented yet

Table 2.3 Main water resources development scenarios

For additional details, the reader is referred to the Draft Working Paper on Reference Scenario and the modelling reports. It should be noted that the assessment of the 1960 development scenario was not completed due to time constraints and lack of information available from MC.

2.2.2 Formulation of "flood thematic sub-scenarios"

There are three flood thematic sub-scenarios as follows:

- FPF1: Planned Development 2040 without Flood Protection: No change in flood protection ie M3CC without flood protection.

- FPF1: Planned Development 2040 with likely Flood Protection: Flood protection for all urban areas to 1:100 years ARI, flood plain development scenario 1 (most likely flood plain development to 2040)

- FPF2: Flood Protection1 + floodplain development and loss of floodplain storage

2.2.3 Data collection

For the Development Scenario 2000, the Early Development Scenario (EDS-2007) and the Definite and Planned Future Development Scenarios (DFS-2020 and PFS-2040) FMMP have sought details of significant flood protection works, together with floodplain infrastructure likely to significantly affect flooding behaviour (e.g. major road and irrigation embankments across floodplains), from the four Member Countries (MCs).

The FMMP has good information on EDS-2007 flood protection works and floodplain infrastructure across the Lower Cambodian Floodplains and the Mekong Delta of Viet Nam. The FMMP will seek further information on significant flood protection works and floodplain infrastructure along the mainstream reach of the Mekong River from the Chinese border to Kratie.

Regarding planned developments in 2020 and 2040, the FMMP use information on proposed flood protection works and floodplain infrastructure as provided by the four MCs.

In the framework of Task 3 of the Initial Studies, sector reports were prepared describing the existing and future conditions for the floodplains for various sectors. These reports were completed in September 2015. The sector experts for each MC were also requested to collect the data for the flood protection structures for the year 2040.

2.2.4 Meeting with other thematic teams for Impact Assessment

Several meetings were arranged with other thematic teams to determine special requirements for the Impact Assessment including flood behaviour characteristics.

Fisheries

Fisheries emphasize the timing of spawning and start of flooding as the most important aspect for fisheries development. Additionally, the extent of flooding and the duration of flooding is important. Some monitoring locations in the Tonle Sap River connecting the Tonle Sap Lake with the Mekong River are required to monitor the start of the flood season.

Agriculture

The frequency of flooding as well as the intensity (level) and duration are important. But it is difficult for Agriculture to indicate the location where monitoring would be best deployed. Agriculture has an extensive list of possible irrigation projects but has yet to select preferred projects and as such it is difficult to indicate locations for the assessment of impacts on Agriculture.

Navigation

Navigation is more interested in dry season rather than in the flood season characteristics. After every flood season soundings are undertaken between Phnom Penh and the sea. If needed the navigation buoys are relocated or dredging commenced to improve navigation.

A key aspect is the depth of the navigation route along the Mekong River. During the flood season the clearance under bridges and electricity lines becomes critical sometimes requiring cessation of shipping for a short period. Navigation is mainly available for the Mekong River between Kratie and river mouth. Existing IALs will provide sufficient information about the maximum clearance at bridges and electricity poles.

2.2.5 Review of SIMVA findings for villages in the mainstream corridor

The MRC project Social Impact Monitoring and Vulnerability Assessment project gathered information on the flood situation at village level, with an average also shown. The results indicate a very high level of impact of flooding as shown in the Table below. The highest levels of impact are in Thailand and Cambodia, see Table 2.1 below.

		Villages with households that experienced losses or damages from any floods in the last 3 years		% HHs experienced damages from flooding in last 3 years
Country	**Sub-Zone**	**N**	**Row %**	**Mean % of HHs**
Cambodia	Zone 4 A - Subzone Cambodia - Khone Falls to Kratie	20	90.91%	39.33%
	Zone 4 B - Subzone Cambodia - 3S	3	75.00%	49.73%
	Zone 4 C - Subzone Cambodia - Kratie to Vietnam border	12	66.67%	52.60%
	Zone 5 A - Subzone Cambodia - Tonle Sap river	15	68.18%	49.15%
	Zone 5 B - Subzone Cambodia - Tonle Sap lake	18	81.82%	58.78%
	All	***68***	***77.27%***	***49.45%***
Lao PDR	Zone 2 A - Mainstream - Lao	1	2.27%	.
	Zone 3 A - Subzone Lao - Mainstream	0	0.00%	.
	All	***1***	***1.14%***	**.**
Thailand	Zone 2 C - Subzone Lower Thailand	9	40.91%	24.74%
	Zone 2 B - Subzone Upper Thailand	19	86.36%	22.83%
	Zone 3 C - Subzone Thailand - Songkhram	18	81.82%	45.17%

	Zone 3 B - Subzone Thailand - Mainstream	14	63.64%	26.64%
	All	***60***	***68.18%***	***30.71%***
Vietnam	Zone 6 A - Subzone Vietnam - Mekong Delta - freshwater	8	18.18%	30.16%
	Zone 6 B - Subzone Vietnam - Mekong Delta - saline	3	6.82%	34.10%
	All	***11***	***12.50%***	***32.13%***
All		**140**	**39.77%**	**38.96%**

Table 2.1 Villages that have households that have experienced losses and % of HHs in last 3 years due to flooding (Source: Village Profile SIMVA)

According to the SIMVA survey data, the source of flooding is not always from the river (ie fluvial flooding) but the majority of floods in the rural corridor relate to river flooding as shown in Table 2.2 below.

		River overflowed		Lake overflowed		Canal overflowed		Rain water could not drain away		Other		Don't know		All cases	Total days of flooding
Country	**Sub-Zone**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**Mean**
Cambodia	Zone 4 A - Subzone Cambodia - Khone Falls to Kratie	351	56.9%	10	1.6%	159	25.8%	42	6.8%	7	1.1%	48	7.8%	617	17.6
	Zone 4 B - Subzone Cambodia - 3S	76	72.4%	1	1.0%	16	15.2%	5	4.8%	1	1.0%	6	5.7%	105	13.7
	Zone 4 C - Subzone Cambodia - Kratie to Vietnam border	305	56.8%	76	14.2%	39	7.3%	96	17.9%	11	2.0%	10	1.9%	537	46.2
	Zone 5 A - Subzone Cambodia - Tonle Sap river	139	33.0%	38	9.0%	85	20.2%	116	27.6%	23	5.5%	20	4.8%	421	40.2
	Zone 5 B - Subzone Cambodia - Tonle Sap lake	125	26.0%	35	7.3%	42	8.8%	101	21.0%	83	17.3%	94	19.6%	480	33.1
	All	***996***	***46.1%***	***160***	***7.4%***	***341***	***15.8%***	***360***	***16.7%***	***125***	***5.8%***	***178***	***8.2%***	***2,160***	***30.7***
Lao PDR	Zone 2 A - Mainstream - Lao	114	60.3%	34	18.0%	28	14.8%	8	4.2%	4	2.1%	1	0.5%	189	2.0
	Zone 3 A - Subzone Lao - Mainstream	301	56.2%	53	9.9%	33	6.2%	92	17.2%	57	10.6%	0	0.0%	536	14.6
	All	***415***	***57.2%***	***87***	***12.0%***	***61***	***8.4%***	***100***	***13.8%***	***61***	***8.4%***	***1***	***0.1%***	***725***	***10.6***
Thailand	Zone 2 B - Subzone Upper Thailand	184	62.8%	1	0.3%	16	5.5%	59	20.1%	24	8.2%	9	3.1%	293	10.9
	Zone 2 C - Subzone Lower Thailand	45	62.5%	0	0.0%	5	6.9%	17	23.6%	3	4.2%	2	2.8%	72	4.4
	Zone 3 B - Subzone Thailand - Mainstream	101	60.1%	0	0.0%	6	3.6%	53	31.5%	6	3.6%	2	1.2%	168	14.2
	Zone 3 C - Subzone Thailand - Songkhram	253	78.8%	0	0.0%	3	0.9%	60	18.7%	4	1.2%	1	0.3%	321	43.1
	All	***583***	***68.3%***	***1***	***0.1%***	***30***	***3.5%***	***189***	***22.1%***	***37***	***4.3%***	***14***	***1.6%***	***854***	***22.7***
Vietnam	Zone 6 A - Subzone Vietnam - Mekong Delta - freshwater	174	18.6%	151	16.1%	134	14.3%	136	14.5%	209	22.3%	134	14.3%	938	45.5
	Zone 6 B - Subzone Vietnam - Mekong Delta - saline	32	19.0%	28	16.7%	25	14.9%	24	14.3%	35	20.8%	24	14.3%	168	21.1

Table 2-1 SIMVA Analysis of flooding sources in the corridor zones

2.3 Assessment methods

The FMMP has assessed changes in flood characteristics primarily in terms of changes to the frequency distribution of Flood Risk (Damage). Baseline distributions will be developed for:

- The EDS-2007 development situation, which will be used to assess future changes under the DFS-2020 and PFS-2040 cumulative development situations; and
- The PFS-2040 cumulative development situation, which will be used to assess changes under the various thematic sub-scenario development situations.

The FMMP terms ‘flood risk’ as average annual damage (AAD). Changes to flood risk are given in terms of changes to AAD between the baseline and future periods (cumulative scenarios) and between the PFS-2040 cumulative scenario and perturbed variations of that scenario (thematic sub-scenarios).

In addition to formulating flood protection works and floodplain development components of the cumulative scenarios and thematic sub-scenarios, the need for flood protection works for the cumulative scenarios (other thematic areas) and thematic sub-scenarios (all thematic areas).

An example of flood risk calculation for the transboundary floodplain in the framework of the Initial Studies is shown in Figure 2-1. The districts shown in this Figure are those for which district based damage functions can be calculated.

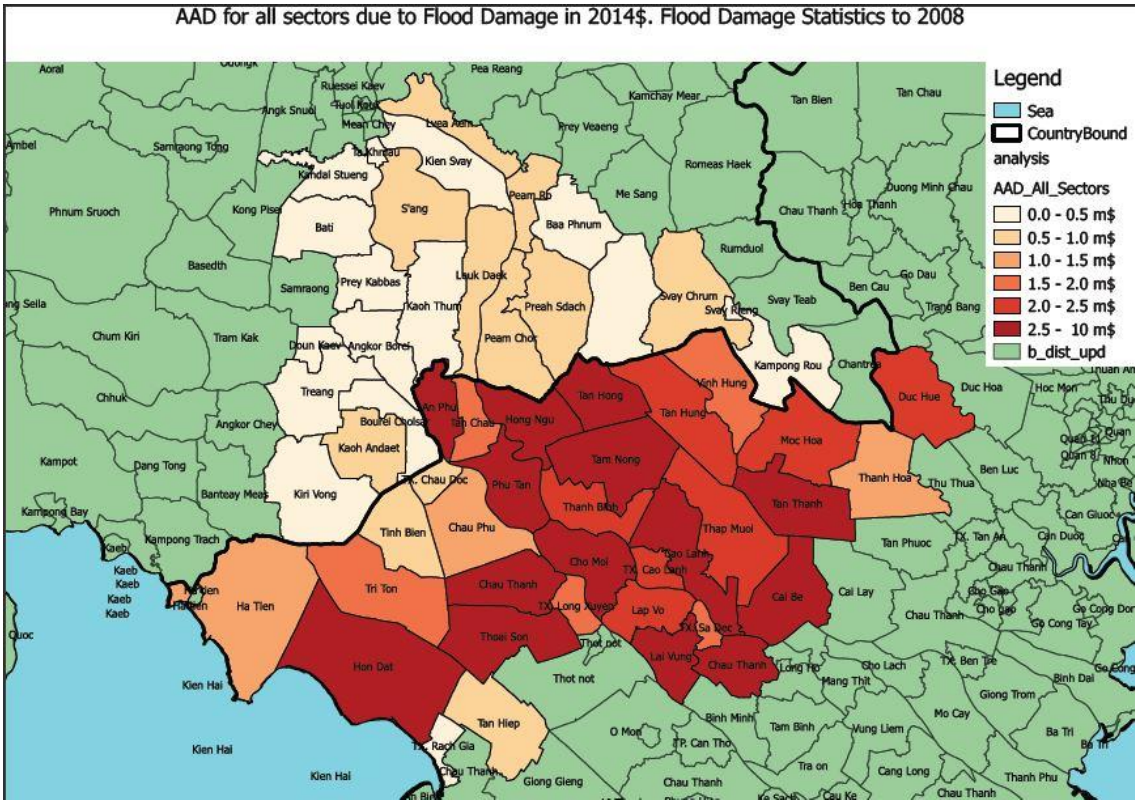


Figure 2.3 AAD of flood damage for reference period 2008 for all Sectors by district.

Direct Damages

The FMMP-C2 study assumed three sectors for flood damage assessment; Housing, Infrastructure and Agriculture. Direct Damage categories associated with these sectors are provided in Table 2.4.

Housing	Infrastructure	Agriculture
Houses **Structures/Commercial** • Cultural/historical structures • Head offices • Market/commercial centres • Warehouses	**Education** **Health** **Irrigation** **Fisheries** **Transport** **Industry** **Construction** **Water & Environment** **Prevention & Rescue (Government +NGOs)**	**Agro-Forest** • Rice paddies • flowers/vegetables • Field crops • Perennial trees • Fruit trees • Seeds • Food • Livestock (large) • Livestock (small) • Poultry • Fertilizers • Agro-chemicals • Eroded land

Table 2.4 FMMP-C2 Sectors – Direct Damage Categories

There is some case for including Fisheries in the Agriculture sector, and that Prevention and Rescue costs should be separated from Infrastructure sector so as to better define residual risk damage costs. However, in the interests of facilitating a comparative analysis between this study and the FMMP-C2 investigations and data collection by the member countries, the FMMP-C2 sector categorization was retained.

Indirect Damages

The FMMP-C2 study also calculated indirect damages for selected districts using household survey data for housing sector indirect costs and data collected through interviews with district and provincial administrative personnel for infrastructure sector indirect costs. No explicit indirect costs were calculated for the Agriculture sector, though they are implicitly included in the infrastructure indirect costs. Flood damages for the 2006 year was used as the basis of indirect flood damage calculation.

A template for the calculation of infrastructure indirect costs is shown in Table 2.5. It was decided for this project that the indirect/direct damage ratios as calculated in the FMMP-C2 studies should be used. The scope of work did not allow for any household or provincial/district administrator surveys within the three months made available to complete this work.

The FMMP-C2 indirect/direct damage ratios are shown in Table 2.6.

	Education	Health	Water Supply	Roads	Irrigation	Electricity	Commercial
Flood Protection	✓	✓			✓	✓	
Emergency Shelters	✓	✓					
Out of Service	✓	✓	✓	✓	✓	✓	✓
Pupils not attend sch.	✓						
Teachers affected	✓						
Customers affected			✓	✓		✓	✓
Temporary Facilities		✓	✓	✓		✓	✓
Additional Costs		✓	✓				✓
Clean up costs	✓	✓					✓
Add. farmer costs					✓		
Farm area not planted					✓		
Cost after flood					✓		

Table: 2.5: Infrastructure Indirect Damage Calculation Template

	Cambodia	Lao P.D.R.	Thailand	Viet Nam
Housing	68%	216%	10%	64%
Infrastructure	19%	39%	7.8%	30%

Table 2.6: Indirect: Direct Flood Damage Ratios

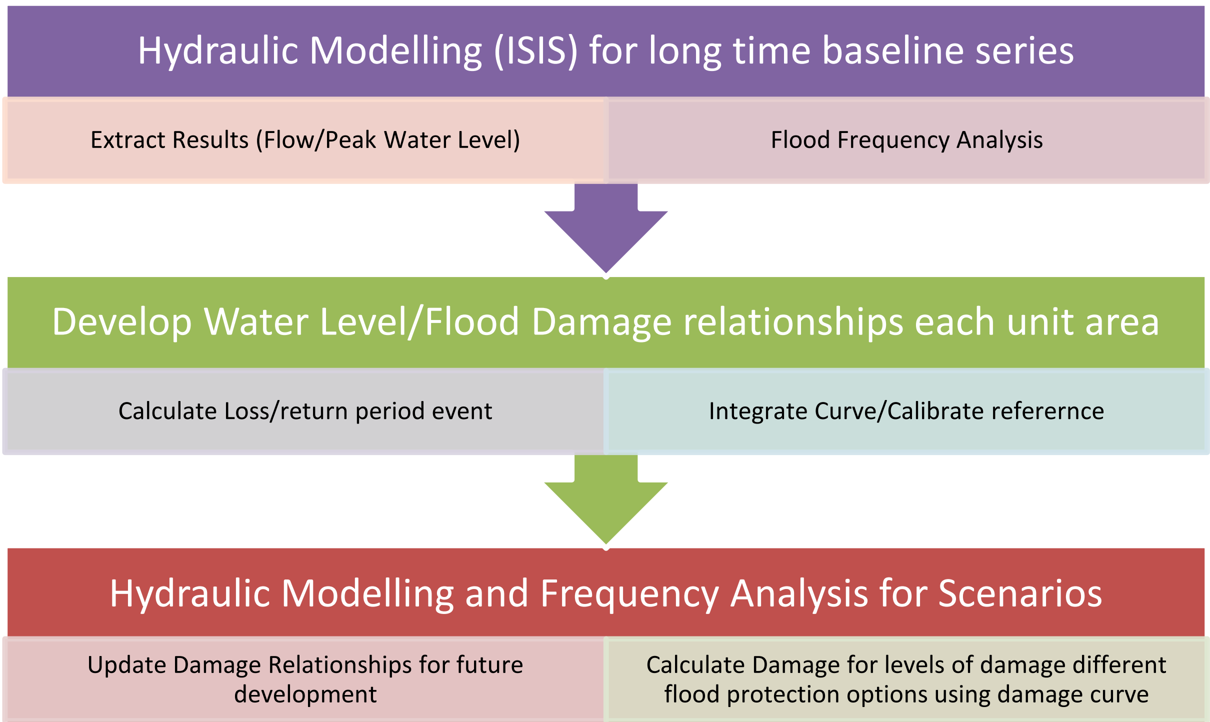
2.4 Flood Damage Estimation for Council Study

Specifically, for the flood sector the flood damages calculation is key to determining impacts especially with regards to flood defences. A process diagram in shown in Table 2.1 and in Figure 2.2 the method for integration of all components of flood damages described above is shown. **The calculation techniques is based on probabilistic analysis of the modelling results rather than looking at specific years.**

Because the modelling results do not have detail on the threshold of flooding, the analysis of results incorporate the flood defence options. This is done in the calculation of flood damage. If flood defences are introduced providing say a protection of annual exceedance probability 10% (1 in 10) year average recurrence interval then damages avoided are that area shown in dark blue to the right hand side of Figure 2.2. We can calculate damages in a similar way for comparison by observing the differences of this curve following climate change or development. Without additional simulation damages avoided through flood protection can then be estimated.

The methodology used is common to the ongoing FMMT 'Initial studies' and further details and capacity building are being provided to Member Countries through that programme. Further details are also given in reports for 'Initial Studies' Task 5 and 6 and the earlier MRC project Component 2 Structural Measures and Flood Proofing in the Lower Mekong Basin May 2010 which is further discussed in Appendix A.

Table 2.1 Process Diagram for Calculation of Flood Damages



In the case of Vietnam and Cambodia sufficient data is available to estimate the flood damages on a district basis (see Figure 2.3) and the results extrapolated to the whole impact corridor.

In the case of Lao and Thailand data to establish the necessary relationships for the Council Study corridor were not available from previous studies at a district level (only two rural districts of the Xe Ban Fai floodplain and samples for Chiang Rai have data) so the member country data was used to establish a likely AAD flood damage for the districts within the corridor and the relationship between current day return period and damage established using data from the sample districts and global sources including the WRI Aqueduct (. The changes in scenario peak flows could then be used to estimate change for different scenarios. The flood damage estimates for the corridor in Lao and Thailand can thus be seen as preliminary estimates for which further study and data collection is desirable.

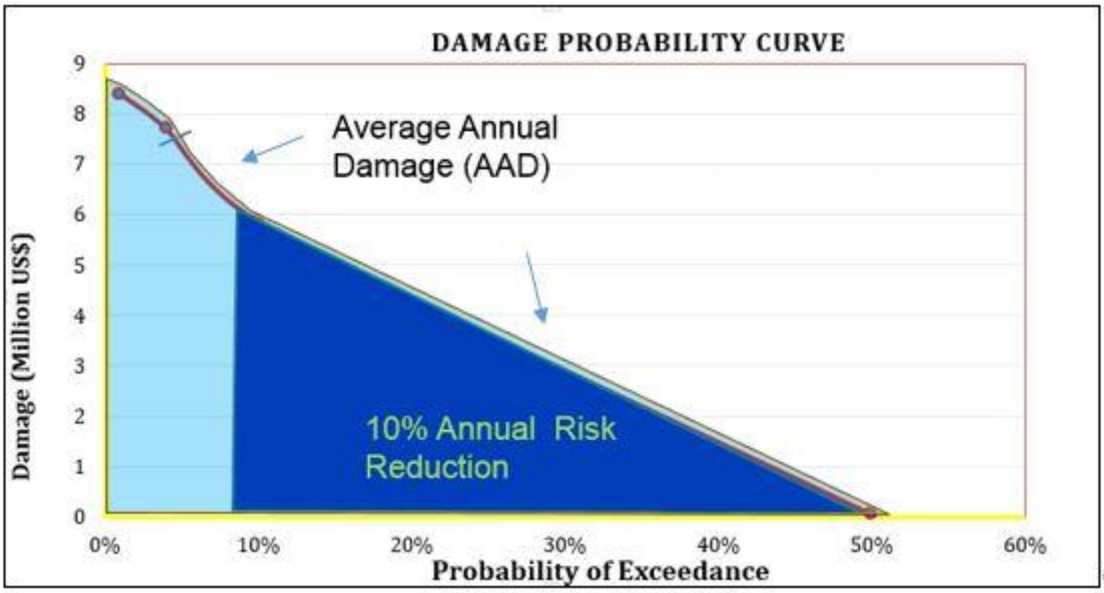


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Figure 2-2 Flood Risk and Damage Estimation for different probabilities are used to estimate an Annual Average Damage (AAD or AED). The effect of flood protection to a certain return period can then be estimated from the curve (area in dark blue)

2.5 Strategic indicators

Strategic Indicators must take account of the triple bottom line assessment and other sector analysis in the CS. For the flood sector specifically, Flood Risk is the key indicator– expressed in terms of a probabilistic analysis of flood damages at different frequencies of probability of occurrence. For flood and river bank protection an assessment is required of damages avoided through improving flood defence infrastructure. People and social aspects should also be a key part including the number of people directly and indirectly affected by floods, impact on the economy etc. Five groups of indicators were thus proposed though not all were possible to calculate at this stage:

- **Hydrological**
  - -Changes in flood frequency at key stations and Impact Assessment Locations
  - -Changes in timing of flood peaks and travel time
  - -Changes in flood duration and depth

- **Flood Risk/Economic Damage**
  - -Crop Damages (Annual Average and Extreme Flood)
  - -Property & Infrastructure and Indirect Impacts
- **Socio Economic**
  - -Food Security implication of flood
  - -Number of People Affected
- **Environment**
  - -Effect of flood protection on fisheries and OAA
  - -Sedimentation reduction due to flood protection
  - -Length of Bank at Risk of Erosion

2.6 Data Gaps

Despite previous studies of the MRC the data available for a comprehensive analysis of flood protection requirements is very sparse at the MRC and there has been a disconnect between the physical hydrology of the main river that has significant data and for example the location and standard of flood protection which is almost totally lacking. The analysis of the need and future cost benefit of flood defence for the corridor can thus only be a first estimate that demonstrates the order of magnitude of the issue and the impact of changes with development.

The MRCS maintains the shared models of the MRC within a suite called the DSF. These models are periodically updated, calibrated to set criteria and scrutinised and approved for use by experts of the member countries. This process reduces the uncertainties associated with the modelling process itself and increases confidence in the established modelling technques. For the Council Study the WUP FIN tools were further developed as described in the accompanying modelling reports. The WUPFIN tools extend the capability of the DSF tools into agricultural production modelling, fisheries of the Tonle and floodplain sedimentation as required by the BioRA team. The capacity of the DSF models themselves were also used to a greater extent than has been done before including sediment and nutrient movement modelling. For the flood flows and water levels a relatively high degree of confidence may be placed in the simulation results.

The socioeconomic data relating to flooding under SIMVA relates to sampling of rural villages and gives a valuable insight into the vulnerable people but is difficult to interpret as a whole corridor going into a likely future of development, improved livelihood and urbanisation.

The development of the floodplain is being studied under the FMMT Initial Studies. Whilst it had been anticipated that new information would be available for the Council Study as yet this is not the case and thus only very preliminary simulations and conclusions can be drawn for the Council Study regarding floodplain development. Because of this limited information the modelling team results available only incorporate limited floodplain changes and the flood benefits and damage assessment makes use of calculation of possible damages that can be avoided for given levels of flood protection rather than further simulations.

The sediment and erosion issue predicted by the modelling indicates a very severe change in the sediment regime but the likely extent and magnitude of impact has not yet been studies in any detail. That extensive protection works will be required seems to be well established though the speed of construction needed in the downstream following the construction of dams needs further geomorphological study that is needed for the assessment of works required and determining the influences including sand mining and flood plain development as well as reservoir sedimentation.

The mainstream dams are likely to be operated to avoid flood impacts upstream or downstream. These impacts are highly dependent on the individual characteristics. The Xayaburi dam for example will operate at a lower level when there is a threat of flooding in Luang Prabang and Pak Beng is proposed to operate at a lower level to avoid dry season impact. Further specific operating regimes are likely at other dams but as yet no information is available for these.

The operating regime of storage dams can affect the flood impact downstream especially at more frequent events. Certain assumptions have been made by the modelling team in deriving operating rules and further development and consultation to improve these using real operation data is desirable.

The importance of extreme events for flooding necessitates long records and though the simulation period for the Council Study is longer than previous studies, 24 years is still relatively short for studying flood frequency.

The WUPFIN tools (see Council Study modelling reports Volume 9) have incorporated flooding into the simulation of agricultural outputs and these are used in a composite form for the social and economic assessment. The flood sector team were unable to confirm the impacts predicted against the expected agricultural damages from the district level analysis and further work is needed to ensure the tool uses good information for planting dates, plant susceptibility to damage, value of the silt carried in floods and impact on groundwater etc.

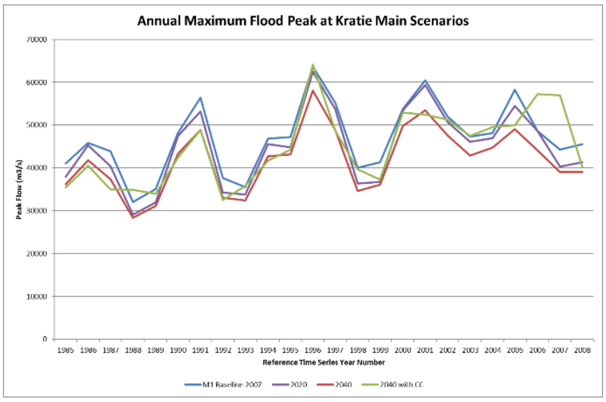
The positive impact of floods for fisheries is also a gap that needs to be more specifically studied with the BioRA tools so that it may be specifically linked with proposed blockages to the movement of floodwater at tributary confluences and floodplain compartments.

3 Scenario Results

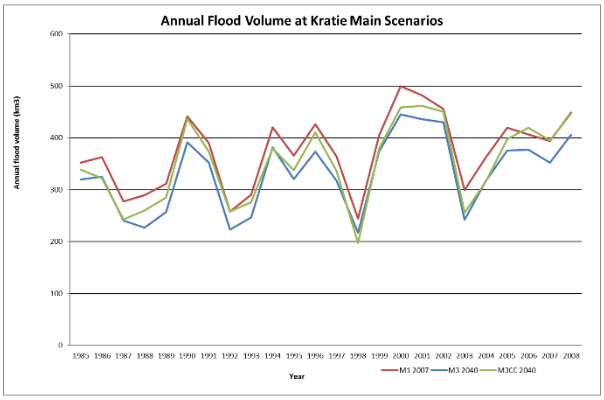
3.1 Main Scenario Flows and Water Levels

3.1.1 Frequency Analysis

The main scenario flows and water levels at key stations from Chiang Saen to the sea were extracted from the isis models and analysed probabilistically for return period and changes with scenario. The annual maxima are extracted from the 24 year time series and then a probability distribution is fitted to each series (Log Pearson Type III is used). From this probability distribution the different return period events are derived for each location and each scenario.



Annual Peak Flow



Annual Flood Volume at Kratie

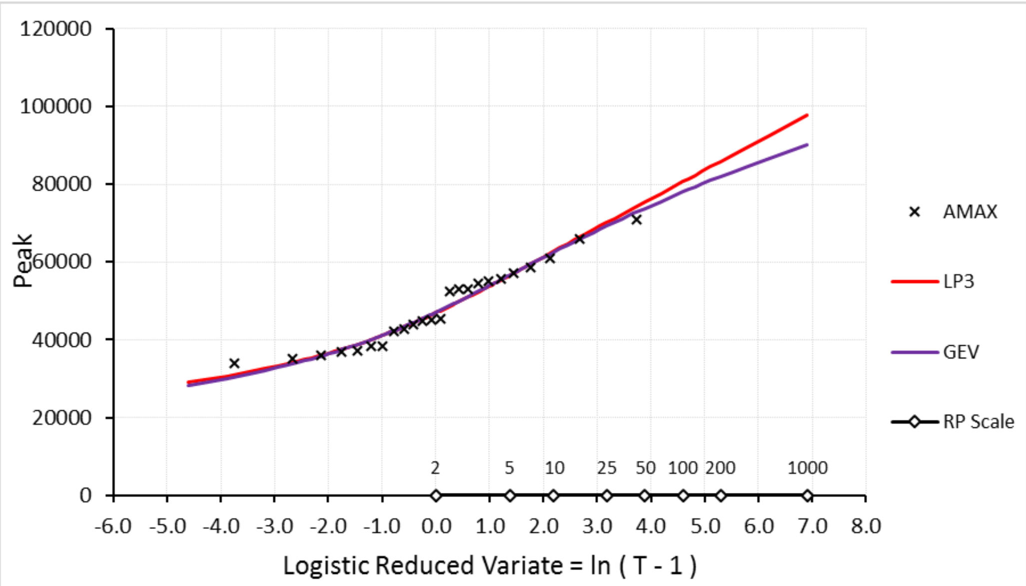


Figure 3-1 Example annual maxima flood peak and volume and the fitting of frequency distributions

In general it was found that the frequency estimates indicate a decline in flow at lower return periods (such as 1:2 year or 1:5 year flood peak) and less change at higher return period events especially in the lower part of the basin. However as shown in Table 3-1 the situation is more complex and can vary from one station to the next. The central seasonal change in climate to 2040 (M3CC) gives significantly higher flood peaks which are more extreme at higher return periods (ie 1:100 year event) and at the higher reaches of the basin Chiang Saen to Vientiane.

Summary Table	M1 5yr	Change M2	M3	M3 CC	M1 100yr	Change M2	Change M3	Change M3 CC
ChiangSaen	11,242	-3%	-3%	13%	13,313	-3%	-3%	43%
Luang Prabang	16,778	-2%	-4%	5%	21,090	-2%	-5%	7%
Chiang Khan	18,855	-6%	-6%	7%	20,979	-3%	-3%	35%
Vientiane	18,456	-5%	-3%	9%	19,522	-1%	-2%	30%
Nong Khai	17,955	-5%	-5%	5%	18,902	-4%	-4%	16%
Nakhon Phanom	26,293	-5%	-5%	0%	29,001	-4%	-5%	-6%
Mukdahan	29,482	-3%	-3%	1%	30,739	-1%	-2%	8%
Pakse	40,078	-3%	-2%	4%	45,240	0%	0%	10%
Kratie	54,703	-3%	-3%	5%	63,163	0%	1%	16%
KPCham	49,131	-4%	-3%	4%	54,788	-1%	0%	15%
Phnom penh	40,367	-2%	-2%	1%	41,839	-1%	0%	5%
PP Basac	6,895	-4%	-4%	2%	7,474	0%	0%	11%
PrekDam	8,119	-6%	-6%	-2%	9,653	-3%	-2%	-3%
KohKhel	2,157	-2%	-2%	0%	2,260	-1%	0%	1%
NekLuong	29,517	-3%	-3%	2%	31,448	-2%	-2%	11%
KPLuang	6,475	-5%	-5%	-1%	8,726	-3%	-4%	-2%
ChauDoc	7,082	-4%	-4%	0%	7,591	-1%	-1%	8%
TanChau	23,914	-2%	-2%	1%	24,834	-1%	-1%	7%

Table 3-1 Probabalistic Analysis of Flood Flows for key stations on the mainstream. Changes are shown for the 1:5 year flood and the 1:100 year flood event for main scenarios

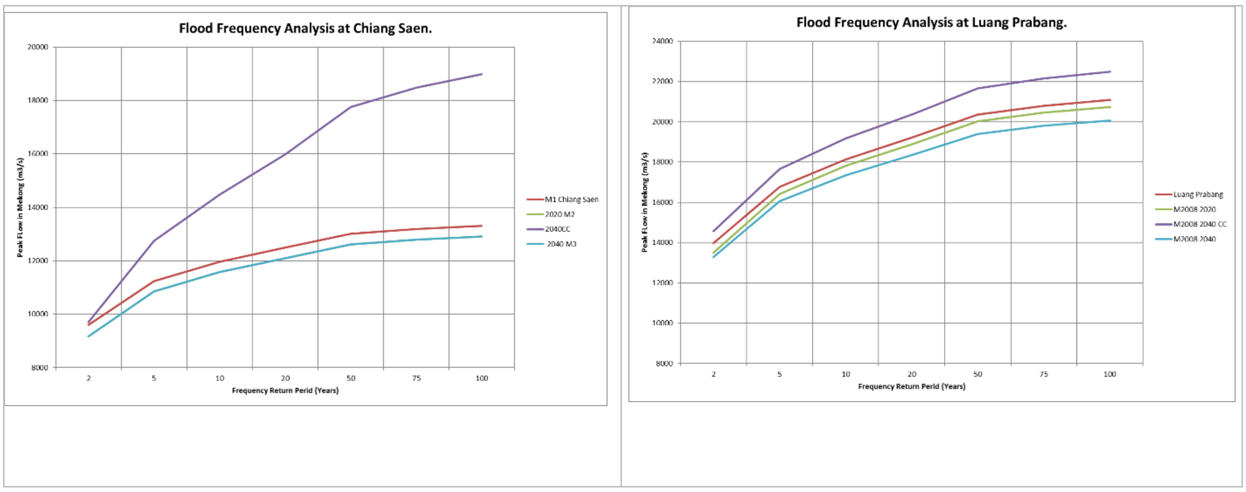
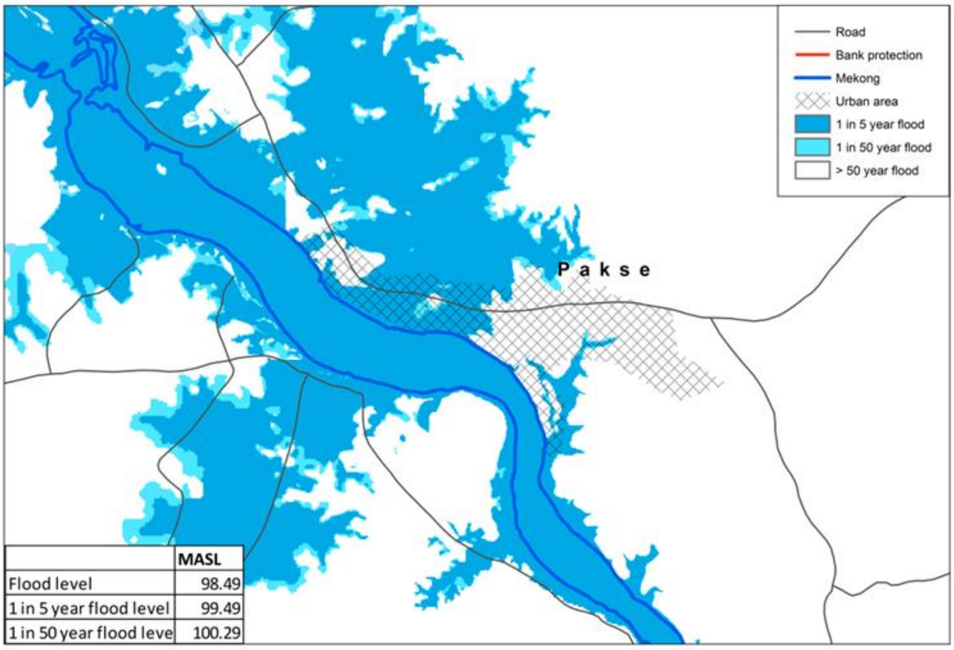


Figure 3-2 Flood Frequency Result Example Plots Chiang Saen and Luang Prabang

3.1.2 Upper Kratie flood mapping

For the flood damage assessment it is not necessary to map the flooding of specific events. For upper part of Mekong River Basin, however a certain amount of mapping was completed to illustrate the extent of the influence of the Mekong and the flooding of existing urban areas. The ISIS model was analysed to give 1:100 year levels and this is used in Figure 1.1 showing the lower and upper parts mapped with isis results. In Appendix E the 1:5 and 1:50 year flood levels are plotted for each main urban area within the corridor. This mapping is completed assuming no defences locally and thus that the flood may extend across the area depending only on the topography. Significant flooding is predicted from this exercise and illustrates the need for better knowledge of existing and planned defences.



The future

Figure 3-3 Expected FLooding at PAkse for 1:5 and 1:50 year flood levels if there are no flood defences relative to the built up urban area.

3.1.3 WUPFIN flood mapping

Flood mapping was needed for BioRA and agricultural assessments so further approximates maps were prepared as detailed in those reports.

Figure 3.7 shows the flood probability. Most areas are flooded permanently, that is they can be considered as the river channel but floodplains in the middle of the region are only flooded for the baseline scenario due to decrease peak flow in the 2020 and 2040 scenarios.

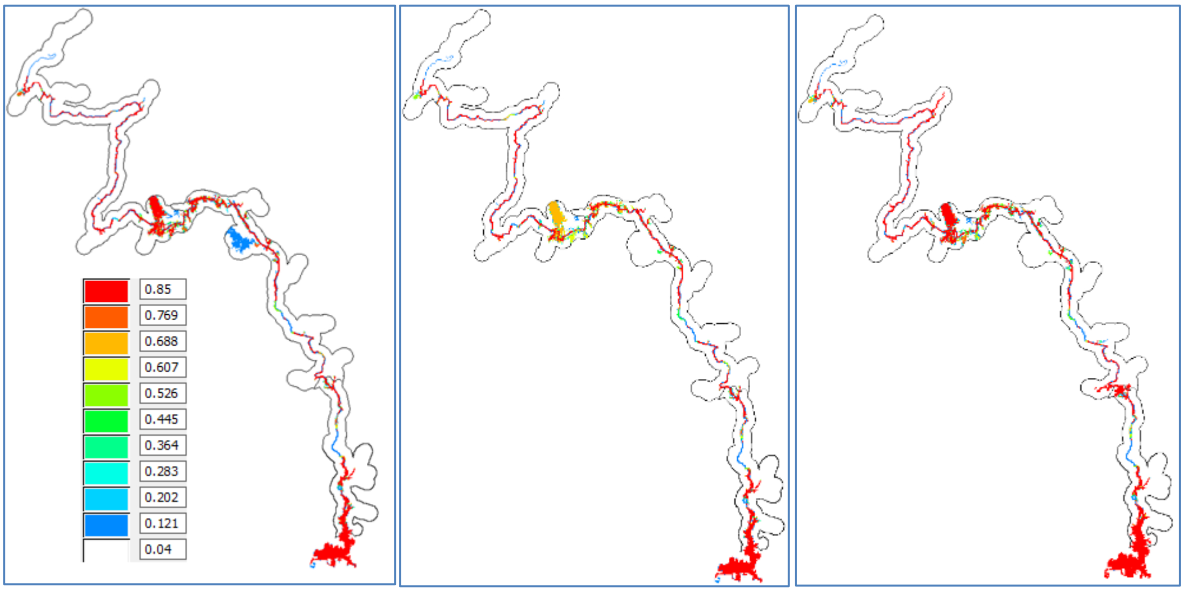


Figure 3-7 WUPFIN Map of probability of floods for the three scenarios (Baseline, 2020 and 2040)

3.2 Main Scenarios Mapping of Flood Results below Kratie

Flooding in the lower basin have been analysed in 2 ways: firstly looking at specific years using the analysis provided by the modelling team and secondly to analyse the flood peaks in a statistical way at a district level that does not require mapping.

Analysing the most severe flood event in the Council Study reference time series which is estimated as approximately 1:20 years at Kratie, the change in flooded areas and duration for the future

FLOOD DEPTH	CHANGE OF THE MAXIMUMFLOOD DEPTH IN COMPARE WITH BASELINE 2000 (1000ha)		
	Dev 2020	Dev 2040	Dev 2040CC
None Flood	-9.56	71.22	35.88
0.0 - 0.5 m	-17.99	16.21	-7.55
0.5 - 1.0 m	52.53	-13.03	-25.22
1.0 - 1.5 m	20.52	2.51	12.70
1.5 - 2.0 m	15.48	16.88	-2.76
2.0 - 2.5 m	-4.53	-8.72	1.41
2.5 - 3.0 m	-23.09	-26.40	-10.02
3.0 - 3.5 m	-19.85	-22.64	-12.52
3.5 - 4.0 m	-0.72	2.12	0.63
> 4.0 m	-12.78	-38.15	7.46

scenarios are given in Table 3.1 below.

Table 3-2 Change in Flood Area and depth for a severe 1:20 Flood

It can be seen that without climate change the scenarios for 2020 (M2) and 2040 (M3) are projected to result in less deep floods that also translate to shorter duration of flooding. However, when comparing with climate change taken in to account flooding increases in most categories.

Considering a more average flood year as shown in Table 3.2 the deeper floods increase significantly for 2020 and 2040 Scenarios with Climate Change. This is unexpected but suggests some shifts in location of floods as there are also reductions in flood areas in the 2020 Scenario. These results are plotted in Figures 3.5 and 3.6.

FLOOD DEPTH	CHANGE OF THE MAXIMUMFLOOD DEPTH IN COMPARE WITH BASELINE 2007 (1000ha)		
	Dev 2020	Dev 2040	Dev 2040CC
None Flood	-353.39	127.83	-259.97
0.0 - 0.5 m	-121.03	32.54	-219.73
0.5 - 1.0 m	56.45	6.16	-35.16
1.0 - 1.5 m	-22.59	-37.92	-30.64
1.5 - 2.0 m	-6.96	25.50	-14.78
2.0 - 2.5 m	-62.09	-72.04	23.54
2.5 - 3.0 m	5.70	6.45	158.17
3.0 - 3.5 m	-44.66	-35.86	41.40
3.5 - 4.0 m	16.96	24.93	50.57
> 4.0 m	531.62	-77.58	286.62

Table 3-3 Change in Flood Depths for an Average Flood Event

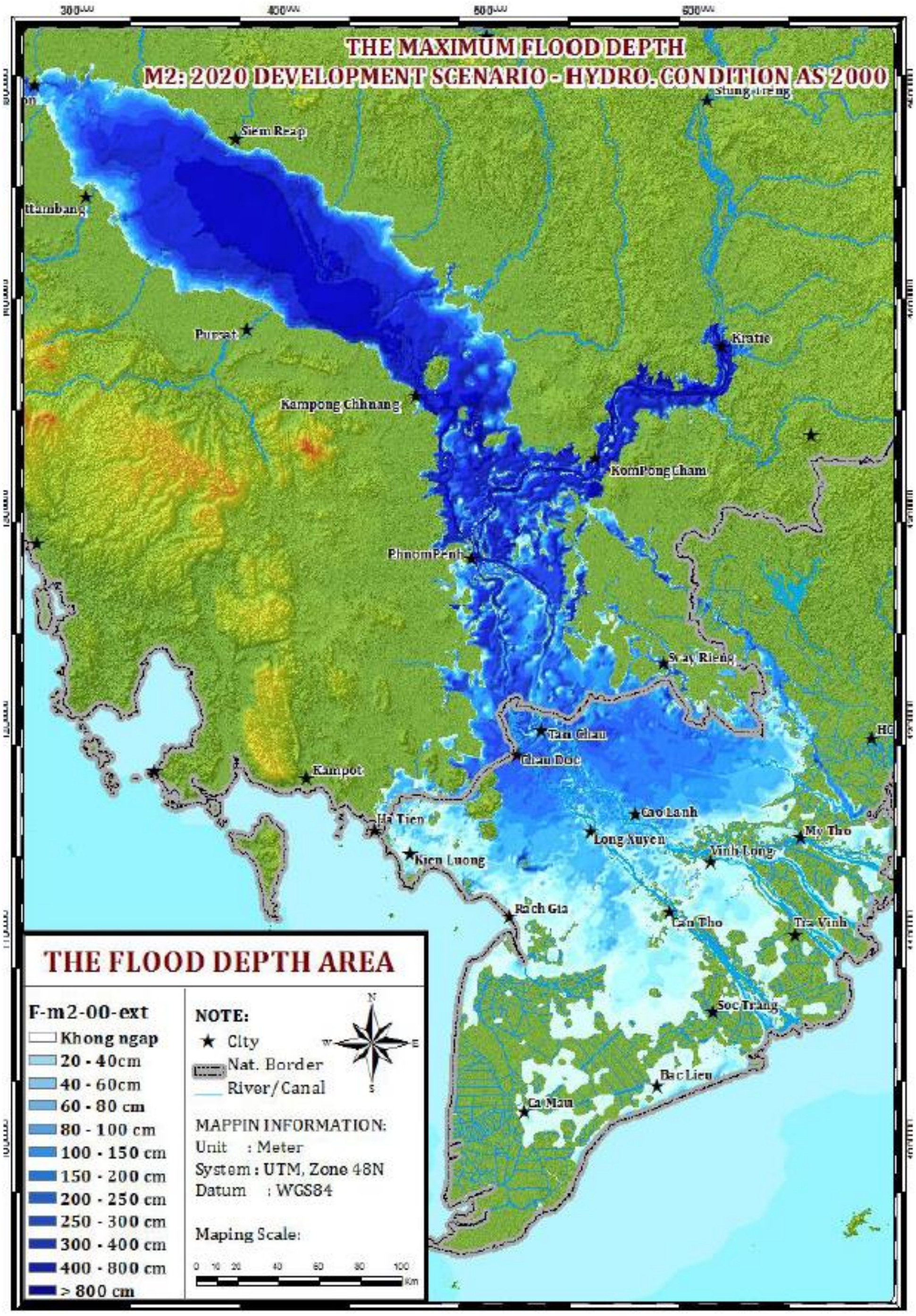

THE MAXIMUM FLOOD DEPTH
M2: 2020 DEVELOPMENT SCENARIO - HYDRO. CONDITION AS 2000
Siem Reap
Pursat
Kampong Chhnang
Kratie
KomPong Cham
PhnomPenh
Svay Rieng
Tan Chau
Chau Doc
Kampot
Ha Tien
Kien Luong
Cao Lanh
Long Xuyen
Vinh Long
My Tho
Rach Gia
Can Tho
Tra Vinh
Soc Trang
Bac Lieu
Ca Mau
THE FLOOD DEPTH AREA
F-m2-00-ext
Khong ngap
20 - 40cm
40 - 60cm
60 - 80 cm
80 - 100 cm
100 - 150 cm
150 - 200 cm
200 - 250 cm
250 - 300 cm
300 - 400 cm
400 - 800 cm
> 800 cm
NOTE:
City
Nat. Border
River/Canal
MAPPIN INFORMATION:
Unit : Meter
System : UTM, Zone 48N
Datum : WGS84
Maping Scale:
0 10 20 40 60 80 100
Km

Figure 3.5 Flood Map for M2 Scenario

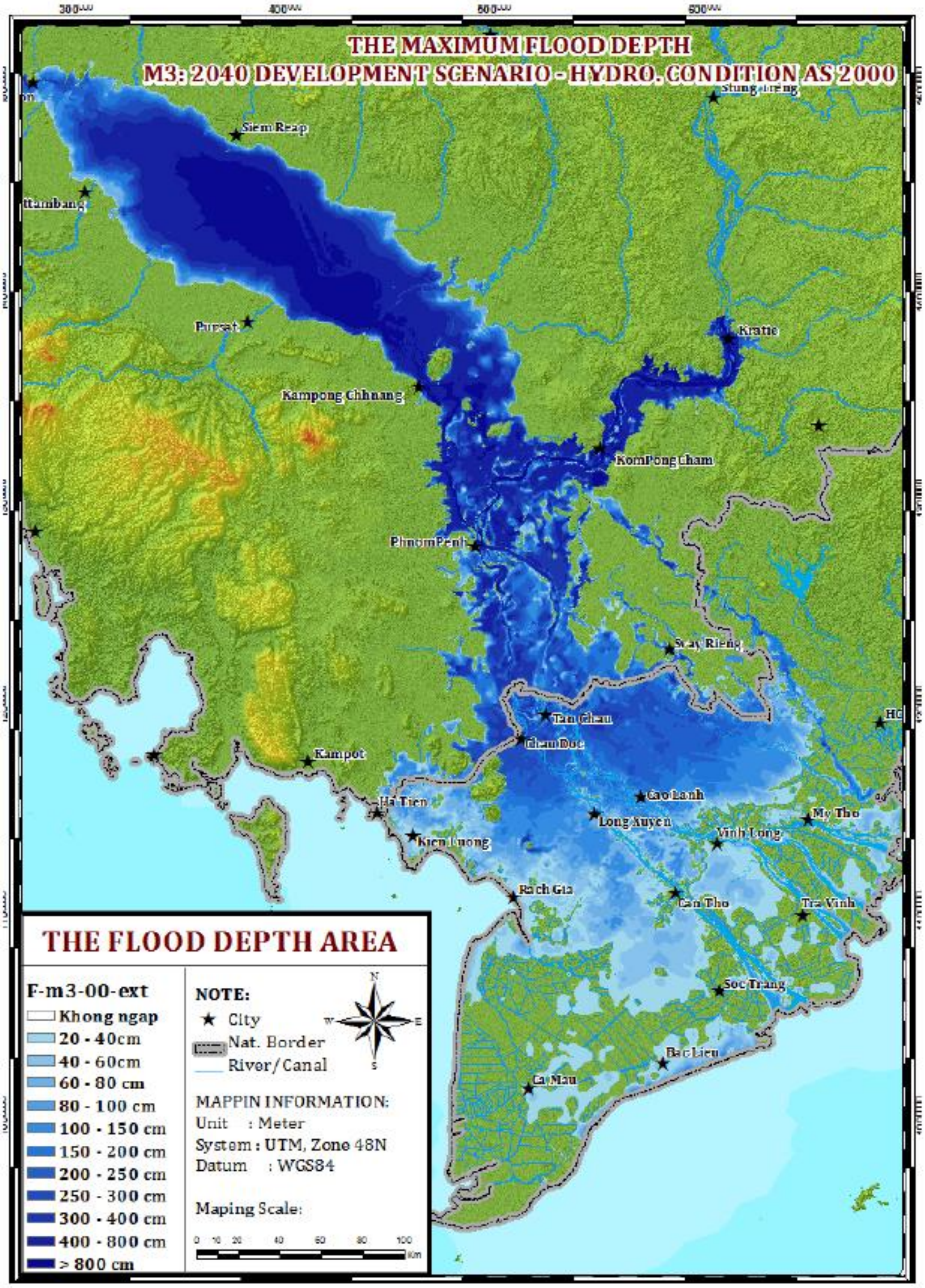


Figure 3.6 Flood Map for 1:20 year event M3 CC Scenario

3.3 Calculation of Flood Damages for Main and Sub Scenarios

3.3.1 Approach

The approach used for damage assessment is a top down one similar to used by the FMMT for which training and tools are provided to Member Countries. The principle is for working with the observed damages divided into categories and water level for events at key locations 'Impact Assessment locations'. Data was collected from member countries for flood events and damage and analysed. The data supplied did not cover the whole corridor especially in Cambodia and Vietnam so it is not possible to have a complete analysis of the whole corridor. For Vietnam and Cambodian districts shown in Figure below the detailed water level depth relationships were defined. For Laos and Thailand the relationship was generalised for all districts so is a more simplified approach reflecting limited data available.

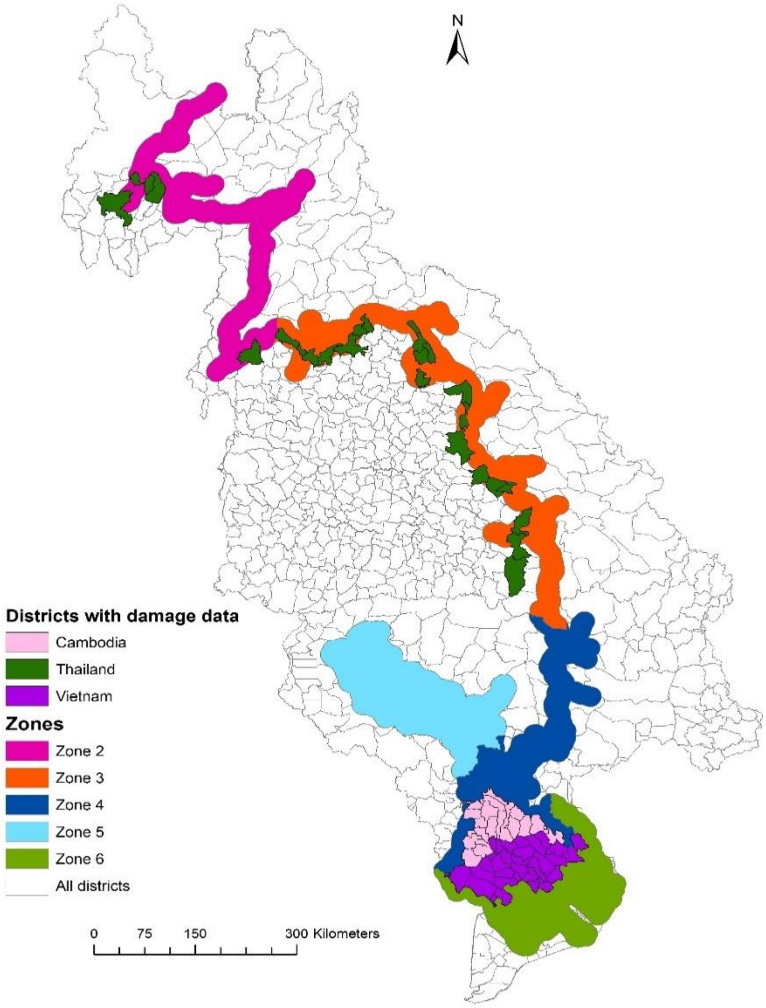


Figure 3-4 Districts with flood damage data available.

The calculation made use not only of the historic condition but was set up to allow adjustment for a changing socioeconomic state that has significant impact.

3.3.2 Flood damage Results – Cambodia

The data available from member countries cover the transboundary area of Cambodia and Vietnam well but this is only part of the corridor. The detailed calculation can be done only for the transboundary area which is then treated as a representative sample and the data presented is factored up to the whole corridor.

In Cambodia it can be seen that relative to population very high losses can occur and there is a tendency for some scenarios to increase greatly the flood risk ie M3CC 2040 increases from 2010 by $42m from $5m at risk in 2010.

Agriculture remains an important component though in future average damages increase sharply for the infrastructure and property with development and commercial activity in this flood prone area. The important impact of flood defences on reducing the annual average damages can be seen comparing F1 and F2.

Table 3-4 Cambodia Flood Damage Estimates Million $. F2 includes additional defences to give 1:100 year protection in urban areas and 1:10 year in agricultural areas

Corridor Cambodia	Socio economic Development	Water Infrastructure	Annual Average Damage ($m)		
	Year	Year	Agriculture	Other&Urban	Total
Scenario M1	2010	2007	4.6	4.1	8.7
Scenario M1	2040	2007	6.4	34.4	40.9
Scenario M2	2010	2020	2.8	2.6	5.4
Scenario M2	2040	2020	3.9	21.6	25.5
Scenario M3	2010	2020	2.8	2.6	5.4
Scenario M3	2040	2040	3.9	21.7	25.6
Scenario M3 CC	2010	2040	6.5	5.3	11.8
Scenario M3 CC	2040	2040	9.1	44.0	53.1
Scenario C2	2010	2040	14.4	14.1	28.5
Scenario C2	2040	2040	20.0	118.2	138.2
Scenario F1	2010	2040	8.9	7.2	16.1
Scenario F1	2040	2040	12.4	60.1	72.4
Scenario F2	2010	2040	3.8	0.6	4.5
Scenario F2	2040	2040	5.3	0.7	6.0
Scenario F3	2010	2040	16.8	16.8	33.6
Scenario F3	2040	2040	23.4	$ 141.16	$ 164.52

Table 3-5 Flood Damages Cambodia – With/Without Flood Protection in all scenarios and effect of a single high event that is greater than defences standard

Corridor Cambodia		Socio economic Development	Water Infrastructure	Scenario Annual Average Damage ($m)	AAD Defences AG 10yr Prop 100 year	($m) Event damage in Extreme Flood
		Year	Year	Total	With Defenses	1:100yr+
Scenario M1		2010	2007	8.7	2.6	21.3
Scenario M1		2040	2007	40.9	3.5	213.6
Scenario M2		2010	2020	5.4	1.6	10.2
Scenario M2		2040	2020	25.5	2.1	109.8
Scenario M3		2010	2020	5.4	1.6	10.5
Scenario M3		2040	2040	25.6	2.2	113.0
Scenario M3 CC		2010	2040	11.8	4.1	31.7
Scenario M3 CC		2040	2040	53.1	5.5	325.0
Scenario C2		2010	2040	28.5	7.0	117.1
Scenario C2		2040	2040	138.2	9.3	557.2
Scenario F1		2010	2040	16.1	4.5	75.7
Scenario F1		2040	2040	72.4	6.0	325.0
Scenario F2		2010	2040	4.5	Already	75.7
Scenario F2		2040	2040	6.0	Already	329.7
Scenario F3		2010	2040	33.6	7.0	117.1
Scenario F3		2040	2040	$ 164.52	9.3	557.2

In Cambodia it can be seen that relative to population very high losses can occur and there is a tendency for some scenarios to increase greatly the flood risk ie M3CC 2040 increases from 2010 by $42m from $5m at risk in 2010. Although the F2 scenario is the main one with flood defences included the effect of these can be calculated for other other scenarios assuming there is not too much change in peak water level at high floods. This information is thus presented in Table 3-7. Also shown is the estimated damage caused by a single high return period event that overtops defences.

A high extreme flood could also set the country development back as it causes up to $557m of damage in a single event which a high proportion of the government budget for the country to afford.

3.3.3 Flood damage Results – Lao PDR

The corridor for Lao and PDR used in the assessment are relatively limited but include both rural and urban areas. Results summarised for Laos below as an example show that with 2007 socioeconomic condition (Table 3-3) the damages to crops dominate the flood risks. However, with development and urbanisation the Urban Risks become more dominant (Table 3-4) though flood defences can significant reduce and manage these risk (Scenario F2).

LAO	0	0	AAD	Including Defences	0	No Defences	Extreme Flood
0	0	Year	Total	Agriculture	Other&Urban	Total	1:1000yr
Scenario M1	0	2007	5.10	2.89	2.21	5.34	49.52
Scenario M2	0	2007	5.30	4.18	1.12	6.86	57.36
Scenario M3	0	2007	7.44	6.32	1.12	9.10	73.17
Scenario M3 CC	0	2007	19.63	16.57	3.06	24.13	73.17
Scenario F1	0	2007	23.33	16.57	6.76	24.13	73.17
Scenario F2	0	2007	7.16	6.60	0.56	24.13	73.17

$million AAD= Annual Average Damages

Scenario F2 has 1:100 year defences property/infrastructure 1:10 year agriculture

Table 3-6 Calculation of AAD (Million $) for Lao districts along the corridor using 2007 socioeconomic conditions

LAO		AAD	Including Defences		No Defences	Extreme Flood
	Year	Total	Agriculture	Other&Urban	Total	1:1000yr
Scenario M1	2007	5.10	2.89	2.21	5.34	49.52
Scenario M2	2020	6.97	4.18	2.79	10.55	90.80
Scenario M3	2040	10.98	6.32	4.66	16.92	144.10
Scenario M3 CC	2040	29.27	16.57	12.70	45.45	144.10
Scenario F1	2040	44.65	16.57	28.09	45.45	144.10
Scenario F2	2040	8.92	6.60	2.32	45.45	144.10

Table 3-7 Calculation of AAD for Lao Districts using expected socioeconomic condition of 2040

3.3.4 Flood damage Results – Thailand

The Council Study corridor for assessment is a very small part of the areas at flood risk in Thailand and the corridor is a small part of the Mekong Basin that is within Thailand. The data available for calibrating district damage/water level functions is sufficient to estimate the historic annual average damage so reliance was placed on the estimation of the likely changes to this for scenarios. The recorded damages within the Districts of the Council Study are as shown below and average $5.3million with notable peaks in 2002 and 2008.

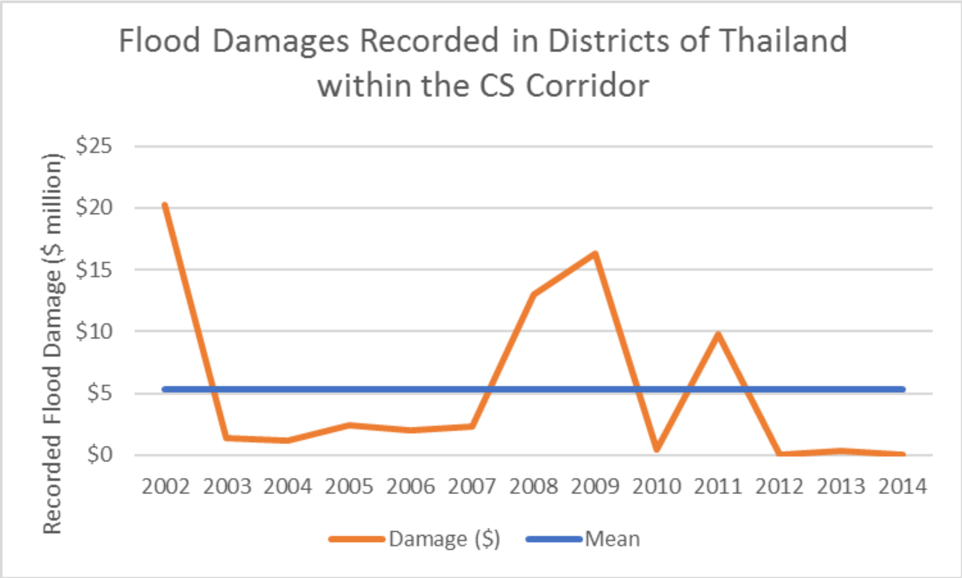


Figure 3-5 Flood damages recorded for the districts of Thailand along the corridor 2002-2014.

For Thailand similar results are obtained as for Lao PDR in 2007 and 2040 condition as shown in Tables 3-5 below. The relatively modest current AAD of $9m increases slightly with M2 and M3 Scenarios but with climate change there is potentially a rapid rise in damage for extreme events for the 2007 condition largely because of agricultural losses though a rise in property/infrastructure is also noted. With the 2040 socioeconomic scenario damages increase further due to the greater value of assets at risk. The F2 scenario shows though that a combination of urban and rural flood defences can mitigate the loss significantly though there is still a residual risk.

2007 Condition

Thailand	0	AAD	Including Defences	0	No Defences	Extreme Flood
0	Year	Total	Agriculture	Other&Urban	Total	1:1000yr
Scenario M1	2007	9.17	5.64	3.52	9.57	82.64
Scenario M2	2007	9.72	7.91	1.81	12.21	94.99
Scenario M3	2007	10.58	8.77	1.81	13.11	125.01
Scenario M3 CC	2007	37.16	32.23	4.93	44.43	125.01
Scenario F1	2007	43.00	32.23	10.76	44.43	125.01
Scenario F2	2007	13.62	12.75	0.87	44.43	125.01

2040 Condition

Thailand			AAD	Including Defences		No Defences	Extreme FLood
		Year	Total	Agriculture	Other&Urban	Total	1:1000yr
Scenario M1		2040	9.17	5.64	3.52	9.57	82.64
Scenario M2		2040	18.66	7.91	10.75	31.74	264.38
Scenario M3		2040	37.71	8.77	28.93	72.35	638.75
Scenario M3 CC		2040	111.14	32.23	78.91	205.99	638.75
Scenario F1		2040	204.56	32.23	172.33	205.99	638.75
Scenario F2		2040	26.71	12.75	13.96	205.99	638.75

$million AAD= Annual Average Damages

Scenario F2 has 1:100 year defences property/infrastructure 1:10 year agriculture

Scenario F1 has no change from M1 ie 1:2 year defences

Table 3-8 Flood Damages Estimated for Thailand part of corridor for 2007 and 2040 Socioeconomic condition

3.3.5 Flood damage Results – Vietnam

Table 3-9 Food Risk Damage Estimates for Vietnam Delta Freshwater areas affected by Mekong Flooding

Corridor Vietnam Fresh water	Socio economic Development	Water Infrastructure	Annual Average Damage ($m)		
	Year	Year	Agriculture	Other&Urban	Total
Scenario M1	2010	2007	5.4	24.8	30.2
Scenario M1	2040	2007	5.2	238.6	243.8
Scenario M2	2010	2020	3.7	16.9	20.5
Scenario M2	2040	2020	3.5	162.0	165.5
Scenario M3	2010	2020	3.6	16.7	20.3
Scenario M3	2040	2040	3.5	160.6	164.1
Scenario M3 CC	2010	2040	9.9	38.8	48.7
Scenario M3 CC	2040	2040	9.5	373.2	382.7
Scenario C2	2010	2040	21.8	56.6	78.4
Scenario C2	2040	2040	20.9	544.1	565.0
Scenario F1	2010	2040	15.2	44.3	59.5
Scenario F1	2040	2040	14.6	425.9	440.5
Scenario F2	2010	2040	9.9	6.6	15.3
Scenario F2	2040	2040	9.5	63.4	72.9
Scenario F3	2010	2040	16.8	33.6	16.8
Scenario F3	2040	2040	21.7	567.6	589.4

It can be seen above that from the difference between F2 in 2040 and F1 in 2040 especially additional flood defences could be used very effectively to reduce the damages especially in urban areas where it is expected that the major growth in risk will occur. In Vietnam this may take the form of a safe urban platforms raised above the flood level. The difficulty with such an approach though is the high fill requirement from the limited supply of sand transported in the Mekong river and if there is a higher flood design level due to climate change and sea level rise then additional banks may be needed. The agricultural damages are relatively high in Vietnam due to the high productivity of the system.

If flood defences were incorporated in other scenarios similar to the 1:100 year protection for urban areas and 1:10 for agriculture then the difference in average annual damage may be estimated as shown in Table 3-9.

Table 3-10 Effect of Flood Protection for different scenarios and the Damage associated with an extreme event

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	Total	With Defenses	1:100yr+
Scenario M1		2010	2007	30.2	2.6	155
Scenario M1		2040	2007	243.8	32.2	1,521
Scenario M2		2010	2020	20.5	3.7	123
Scenario M2		2040	2020	165.5	24.7	1,178
Scenario M3		2010	2020	20.3	3.7	121
Scenario M3		2040	2040	164.1	24.6	1,171
Scenario M3 CC		2010	2040	48.7	4.1	322
Scenario M3 CC		2040	2040	382.7	68.1	3,187
Scenario C2		2010	2040	78.4	18.2	427
Scenario C2		2040	2040	565.0	76.7	3,377
Scenario F1		2010	2040	59.5	15.3	330
Scenario F1		2040	2040	440.5	72.9	3,187
Scenario F2		2010	2040	15.3	Already	335
Scenario F2		2040	2040	72.9	Already	3,314
Scenario F3		2010	2040	16.8	18.2	427
Scenario F3		2040	2040	589.4	76.7	3,377

The extreme flood will always potentially be greater than the defence level and for Disaster Risk Management the total flood risk is shown also in Table 3-9. It can be seen that a major flood in 2010 would have caused a fairly high loss of $155m in 2040 with Climate Change that could increase to over $3billion dollars.

3.4 Results of Biological Resource Assessment for flooding

3.4.1 Ecosystem response to flood-protection infrastructure sub-scenarios

To assess the effect of flood-protection infrastructure on the environment, three different sets of assumptions about flood protection were paired with Scenario 2040CC, and evaluated in terms of their relative impact on the Mekong River ecosystem,

F1_noFPI: 2040CC but with flood-protection infrastructure at 2007 levels;

F2_FPI: 2040CC but with a higher level of flood-protection infrastructure than that modelled in the 2040CC scenario:

F3_FPI: 2040CC with flood protection infrastructure at 2020 and with joint operation of mainstream dams and selected tributary dams to reduce flooding.

The outputs for key BioRA summary indicators for the 2040CC and the three-additional flood-protection sub-scenarios relative to the 2007 Baseline scenario are shown in Figure 3-6.

The differences in the health of geomorphology (habitat quality); vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals in the unimpounded section of the river between 2040CC and the flood-protection infrastructure sub-scenarios are illustrated in Figure 3-7. As expected, the outcomes closely reflect the relative proportions of expected change in floodplain inundation as a result of floodplain protection infrastructure applied for Scenario 2040 and the sub-scenarios, and should be evaluated in the context of these.

Based on the modelled outcomes, beyond a very slight predicted increase in impacts in one or two zones, the changes in the floodplain protection have little or no additional effect on the key BioRA indicators *for the channel* in Zones 1-5. The results for Zones 1, 2, 4 and 5 suggest that, in the context of the Council Study, any impacts on the channel that may have been associated with floodplain infrastructure are masked by the impacts of the other sector developments comprising Scenario 2040CC.

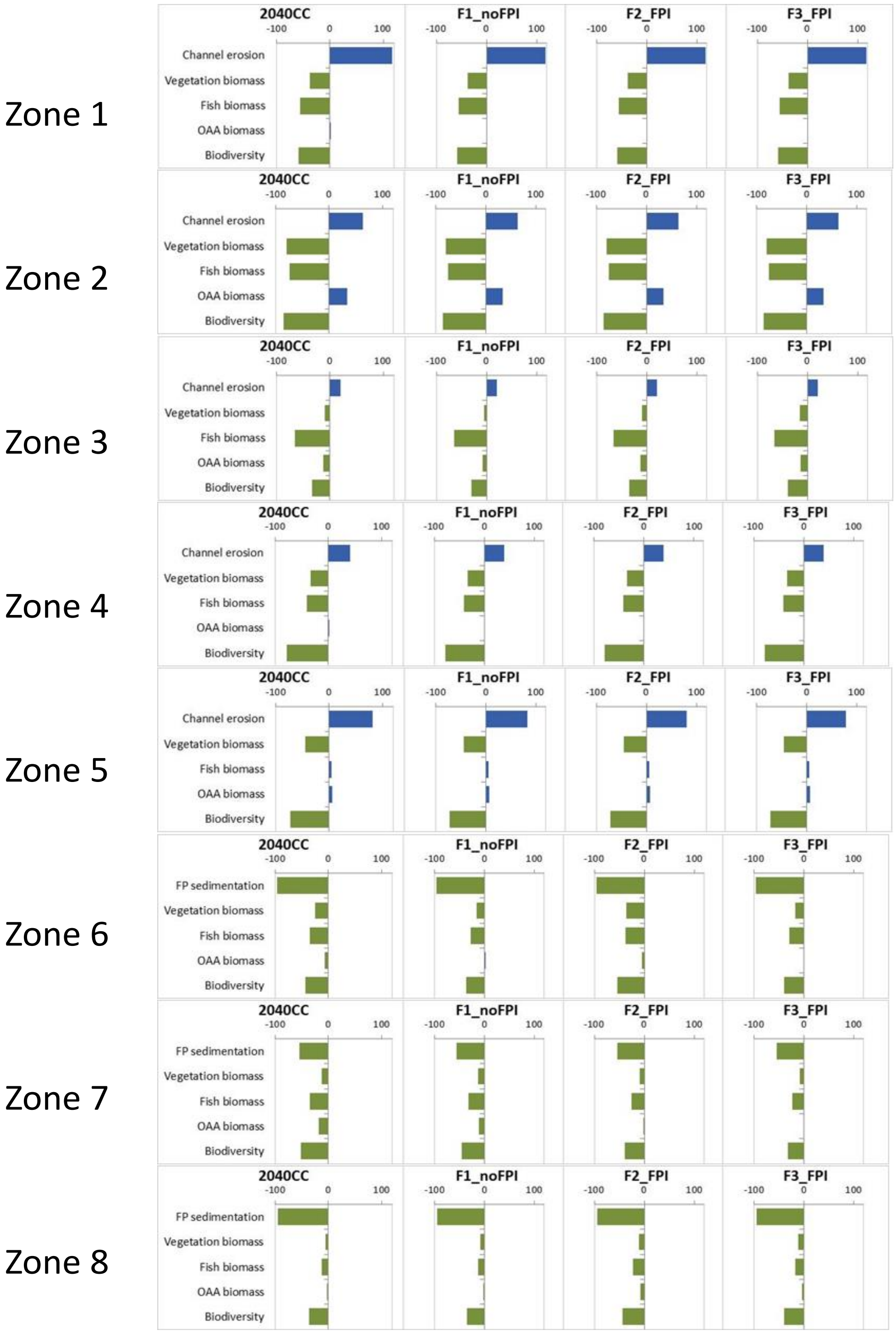


Figure 3-6 Predicted changes from Baseline in key ecosystem indicators for the BioRA zones for the flood-protection sub-scenarios (left to right): 2040CC; F1_noFPI, F2_FPI and F3_FPI. FP = floodplain; OAA = Other Aquatic Animals.

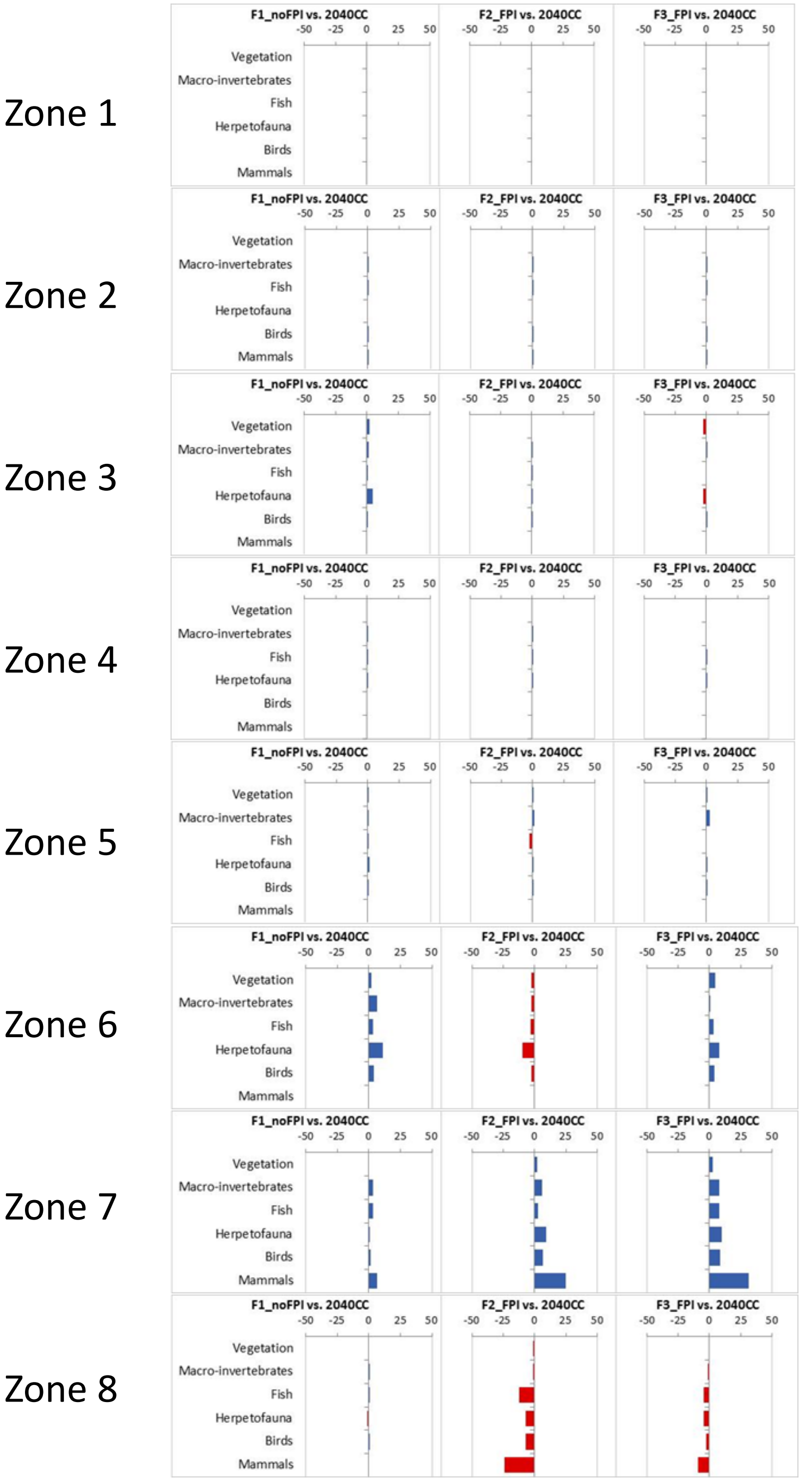


Figure 3-7 Difference in health for vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals between 2040CC and the flood-protection infrastructure sub-scenarios

Canalisation of the Delta, and the development of roads and other raised infrastructure that limit the flow of water onto or within the floodplain, also predates Baseline 2007, and the any influence on ecosystem condition of the relatively small changes in flooding applied for F1_noFPI are masked by the impact of other sector developments (Figure 3-7), which are predicted to considerably reduce the condition relative to Baseline 2007

The floodplain protection infrastructure modelled in F2_FPI is designed to reduce flooding relative to 2040CC and as such is predicted to also reduce habitat for riverine species. leading to a decline in overall ecosystem condition relative to Scenario 2040CC. In Zones 1-6, this influence is minor relative to the other sectors but is more marked in the Delta (Zone 8). In Zone 7, the Tonle Sap Great Lake, there are no physical flooding limitations or defenses applied, and so the F2_FPI leads to greater flooding, presumably as a result of less flood storage in the upstream zones, are thus improved ecological conditions relative to Scenario 2040. Further encroachment into the Tonle Sap Authority outer zones may affect flooding, but this was not accounted for in the modelled scenarios.

F3_FPI has the floodplain infrastructure at 2020 levels but includes synchronised dam operations to reduce large floods. This is expected to lead to more regular homogenous flooding relative to the varied flooding predicted as a result of climate change in Scenario 2040CC. The more homogenous flooding is expected to benefit the large floodplain ecosystems in Zones 6 and 7. In the result for the Delta is more difficult to explain, and is possibly related to the fact that the larger floods overtop the flooding defences, whereas a large proportion of the more regular homogenous floods in F3_FPI are prevented from reaching the floodplain. Thus, floodplain inundation is predicted to be less under F3_FPI than under 2040CC, resulting in the negative consequences of the ecosystem shown in Figure 3-7.

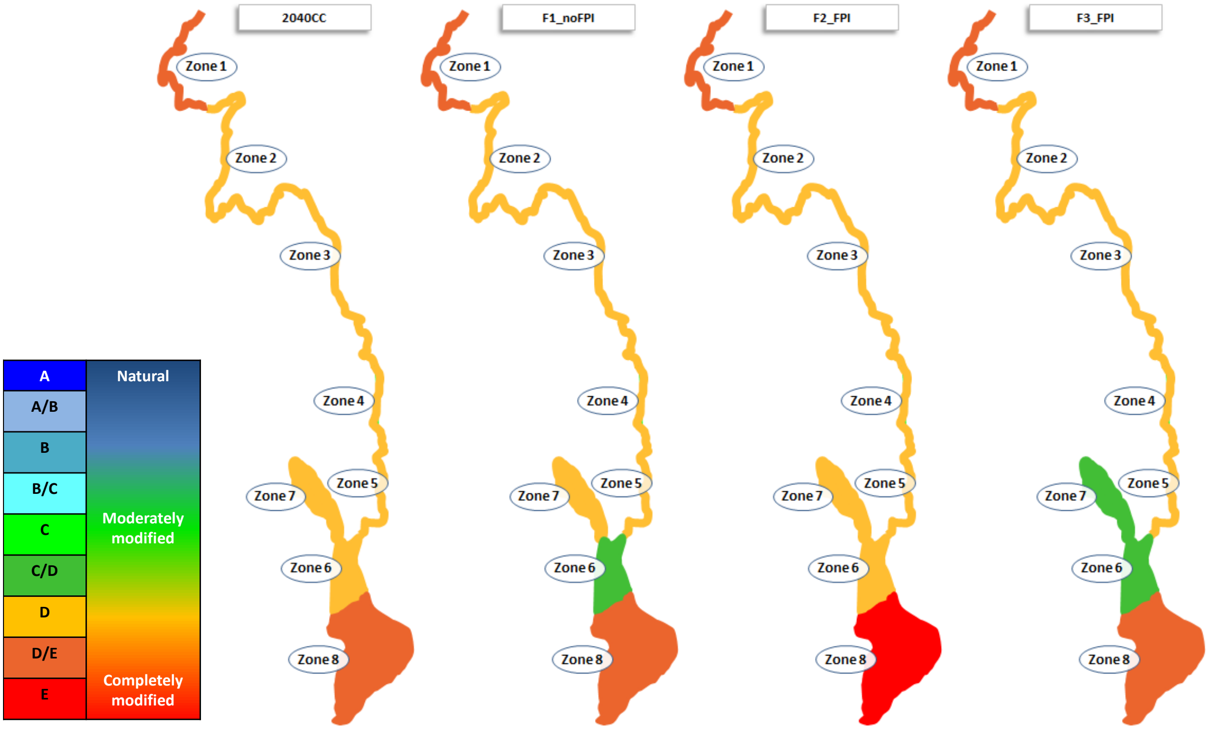


Figure 3-8 Mekong River condition predicted for the flood protection sub-scenarios

3.5 Social and Macro Economic Assessments

For the macroeconomic assessment the cost and benefits of flood defences were estimated and used for calculate net present values and the impact on the economy.

Development gains and increasing investments in infrastructure (e.g. irrigation) imply that more assets are exposed to extreme events, such as floods. This increasing risk can convert into increasing vulnerabilities if no additional protective or adaptive mechanisms is put in place. Floods are an important driver for community vulnerability. shows the net present value of investments in flood protection included in the relevant scenarios. The overall investment by Lao PDR (M2: $23 million; M3: $99 million, M3CC: $119 million) would result in reduced exposure and, thereby reduce vulnerability, and a positive net present value of $162 million for scenario M3CC. Extreme floods (greater than an assumed 1:100 years) would not be averted and would cause damages of around $144 million.

Floods are an important factor for Cambodia and introduces a mix of positive and negative effects. Flood related losses are likely to increase as increasing development involves more assets being exposed and, thereby increasing risk and vulnerability. suggests that the net present value of investments in flood protection is about $337 million for M3CC. The planned investments (M2: $4 million; M3: $482 million, M3CC: $579 million) would mitigate flood related vulnerabilities. Only one-in-a-hundred year events would continue to cause substantial damage, possibly up to $325 million per event.

Floods are a reoccurring driver for community vulnerability across Thailand's northeast. Similar to other parts of the lower Mekong basin increasing levels of private and public investments converts into more assets being exposed and, thereby increasing risk and vulnerability. quantifies the net present value of investments in flood protection at nearly $1.3 billion for M3CC. The planned investments (M2: $83 million; M3: $149 million, M3CC: $178 million) would reduce flood related vulnerabilities. Only one-in-a-hundred year events would continue to cause substantial damage, estimated at around $639 million per event.

Floods are part of life in Vietnam's Mekong Delta and are typically connected with a rage of positive effects (e.g. sediment, nutrients) and negative impacts. While positive effects are projected to decline sharply with upstream hydropower negative effects are likely to be mitigated by substantial investments in flood protection (M2: $36 million; M3: $1 billion, M3CC: $1.25 billion). combines an increasing level of assets exposed to floods, changing flood intensities and frequency, and planned flood protection infrastructure. Resulting net present value of investments in flood protection for M3CC is about $3.8 billion, which indicates that these investments are worth-while considering. However, investment plans would not cover one-in-a-hundred year events, which would cause substantial damages of about $3.2 billion.

Table 3-11 Net Present Value of Flood Sector Investments

	Lao PDR	Thailand	Cambodia	Vietnam	TOTAL
	M$	M$	M$	M$	M$
Scenario M1	$3	$6	$541	$3,061	$3,611
Scenario M2	$38	$139	$335	$2,014	$2,527
Scenario M3	$26	$411	$46	$1,384	$1,867
Scenario M3 CC	$162	$1,264	$337	$3,791	$5,554
Scenario F1	$12	$21	$0	$0	$32
Scenario F2	$355	$2,420	$189	$3,858	$6,821

Environmental conditions decline rapidly with the investment bundles of M2 and M3 as the BioRA report outlines. The majority of impacts on river channel condition and the extent of inundated forests seems to emerge already from M2 if compared with the overall effects of M3 investments. Effects on biodiversity that define an important ecological dimension for human vulnerabilities show more linear effects if comparing M2 and M3 investments. The sub-scenario perspective reveals that the vast majority of these vulnerability related losses are triggered by dams, in particular mainstream dams. Similar to the macro-economic perspective, M1 emerges as the optimal strategy to maintain these boundary conditions of human vulnerabilities. The second best solution is likely to be H1a, followed by H1b.

Another critical environmental driver is the frequency and intensity of floods and the exposure to floods. The flood analysis prepared under the council study highlights that climate change is likely to lead to higher flood peaks under main scenario M3CC due to the increasing variability. This coincides with a larger exposure as development gains and the increasing investment in infrastructure convert into more assets likely to be affected by flood events. However, the proposed flood mitigation investments are likely to reduce risks substantially. Rare floods (1 in a thousand year events) would still cause significant economic losses. Additionally, experience has shown that hydropower cascades are prone to trigger man-made floods, which might severely affect numerous communities. However, in comparison droughts are likely to have larger impacts on livelihoods throughout the lower Mekong basin.

3.6 Erosion

The macro-economic assessment report provides an overview of costs for river embankments that would need to be constructed to avoid hydropower driven erosion. The total costs are estimated to be nearly $5.7B for the 2040 development scenario and $866M for the 2020 scenario.

Table 3-12 Distribution of costs for river bank protection

	Lao PDR	Thailand	Cambodia	Vietnam
Scenario M2	26%	64%	2%	8%
Scenario M3	17%	17%	28%	37%

Table 3-12 quantifies how cost for additional river embankments would distribute among lower Mekong basin countries. Thailand would have to expect the highest share of 64% for the 2020 scenario, around $551M, while Lao PDR would face costs of around $228M.

For scenario M3 the distribution of costs for additional river embankments would shift substantially. Vietnam is likely to face the highest share of 37% (around $2.1B) and Cambodia of 28% ($1.8B).

These costs could be addressed by a burden sharing mechanism. According to the source model,

- 35% of the responsible sediment loss is caused by dams in the Lancang,
- 30% by tributary dams of the lower Mekong basin,
- 32% by mainstream dams in the Mekong, and
- 3% by processes in the Mekong Delta.

A proportional mapping of costs would lead to a levy of 1.20% for mainstream dams and 1.12% for tributary dams. This assumes that Lancang effects $1.98 billion is compensated by alternative mechanisms. If this levy for compensating erosion related costs was combined with the fisheries-focused levy, a combined levy of 9.76% on profits from tributary dams and 20.1% on profits from mainstream dams would result. While this is a broad guide for revised cost calculations it might be impractical to combine both burden sharing mechanisms as the compensation of fisheries costs would need to reach the disadvantaged households while erosion related costs are largely faced by the governments.

The CIA developed a predictive tool for estimating changes in GDP through the full range of scenarios. This is shown in Table 3-13. The flood scenarios all potentially have a positive impact on boosting GDP.

Table 3-13 Contribution and impact of scenarios on GDP

GDP difference (M3CC) in billion US$ (deflated to 2017 dollar)		A1 (2007)	A2 (2020)	C2 (Wet)	C3 (Dry)	I1 (no IRR)	I2 (IRR)	F1 (no FPI)	F2 (FPI)	F3 (FPI)	H1a (noHPP)	H1b (noMain)	H3 (HPP)
Cambodia	Upper bound	**$2.9**	-$0.9	-$1.4	-$1.5	-$1.1	-$1.7	-$0.8	-$0.5	-$0.8	$0.8	-$0.1	-$0.2
	Average	**$9.5**	$2.3	$2.2	$2.3	$2.4	$1.9	$0.9	$1.0	$1.1	$1.7	$1.1	$1.0
	Lower bound	**$16.2**	$5.6	$5.7	$6.1	$5.8	$5.4	$2.7	$2.4	$3.0	$2.5	$2.2	$2.2
Lao PDR	Upper bound	-$0.5	$0.3	$0.0	$0.2	$0.3	$0.1	$0.2	$0.2	$0.2	$3.8	$1.9	$0.1
	Average	**$6.0**	-$0.1	$0.3	$0.4	-$0.1	-$0.2	$0.1	$0.1	$0.1	$2.2	$0.6	$0.0
	Lower bound	**$12.4**	-$0.5	$0.6	$0.6	-$0.4	-$0.6	$0.0	$0.0	$0.0	$0.6	-$0.8	-$0.1
Thailand	Upper bound	-$0.3	$0.3	$0.0	$0.2	$0.3	$0.1	$0.0	$0.2	$0.0	$5.8	$4.5	-$0.2
	Average	**$7.8**	-$1.4	$0.8	$0.5	-$1.4	-$1.4	$0.0	$0.1	$0.0	$2.8	$1.7	-$0.1
	Lower bound	**$15.9**	-$3.0	$1.6	$0.9	-$3.2	-$3.0	$0.0	$0.0	$0.0	-$0.2	-$1.2	$0.1
Vietnam	Upper bound	$0.4	-$0.1	-$0.5	-$0.4	-$0.5	-$0.4	-$0.3	-$0.1	-$0.3	$1.4	$0.7	$0.1
	Average	**$3.1**	$2.8	$2.4	$2.6	$2.5	$2.5	$1.4	$1.6	$1.6	$2.6	$2.7	$0.8
	Lower bound	**$5.8**	$5.7	$5.4	$5.6	$5.4	$5.5	$3.1	$3.3	$3.4	$3.7	$4.7	$1.6
LMB	Upper bound	$2.5	-$0.5	-$1.9	-$1.5	-$1.0	-$1.9	-$0.9	-$0.2	-$0.9	**$11.8**	**$7.1**	-$0.3
	Average	**$26.4**	$3.6	$5.7	$5.8	$3.3	$2.7	$2.5	$2.7	$2.8	**$9.2**	**$6.0**	$1.8
	Lower bound	**$50.4**	$7.6	$13.3	$13.1	$7.6	$7.3	$5.9	$5.7	$6.4	**$6.6**	**$4.9**	$3.8

Flood protection investments seem beneficial and would slightly increase benefits across sectors in the lower Mekong basin with the exception of the fisheries sector in Vietnam, which would decline slightly. Cambodia would account for the largest gains from variations in flood protection with $1.1 billion in NPV for sub-scenario F1.

4 Implications for Planning and Policy

4.1 Transboundary Issues

4.1.1 Flood response to infrastructure sub-scenarios

In Cambodia and Vietnam it is found that the development upstream for scenarios M2 and M3 decrease the average annual flood risk relative to the base M1 case. In Thailand and Lao This is likely to foster a complacency on floods as a declining influence and the sector may become neglected relative to other priorities, if development on the floodplains is allowed then this will create additional obstruction. Therefore when a large flood does occur the flood impacts could be very high due to the additional assets placed at risk and the loss of floodplain.

Infrastructure development and loss of floodplain storage raises flood levels so in sensitive border areas this must be carefully planned. Better land use planning and flood zoning on the floodplain taking account of flood conveyance is needed.

4.1.2 Climate Change

The effect of dams upstream are insufficient to counter the increase in flood severity and frequency expected for a moderate climate change scenario to 2040. Significant increases in damages may be expected so planning for a changing climate must be mandatory for major infrastructure developments.

4.1.3 River Bank Erosion

The significant loss of sediment from upstream is likely to cause major issues with bank erosion in the medium future and extensive lengths of bank protection works are likely to be needed in all countries. Erosion at the Mekong delta coastline will also accelerate. Mitigation at mainstream dams could help to slow down the response. More work is needed on this aspect

4.2 Extreme Flood Events

Flood damages estimated for extreme flood events that overtop defences are likely to cause extensive damage to people infrastructure and loss of life to such an extent that development would be severely set back. Better planning for such events when developing urban areas to minimise impact.

4.3 Development of Flood Defences

The benefits of providing improved flood defence for urban areas are likely to be very high as societies becomes more prosperous. Thus more attention should be paid to provision with allowance for future change.

In rural parts the benefits to agriculture are clear though these do not change much going into the future and the loss in benefit to the environment and increasing water levels elsewhere are likely to limit how much is the optimal level of protection for agriculture.

Flood plain development should take account of the need for flood ways and other pathways for flood storage and flood conveyance during high return period events.

5 Synergies and Uncertainty

5.1 Synergies

The potential loss of sediment with development and the consequent requirement for bank protection works is an ideal opportunity to include flood protection in the work at a modest cost.

The protection of wetlands and forest has a high level of synergy with the flood peak reduction in extreme cases.

Works for climate change adaptation are likely to include flood protection so funds from this source could help the provision of the desirable flood defences.

The possible impact of upstream dam operation on flood reduction would be a synergy but quite how this can be achieved is not clear as initial modelling only suggested releasing flow at the beginning of the season could be deleterious.

5.2 Uncertainties and limitations

The initial stages of work on the Council Study beyond planning and agreement of the approach was to collect more of the data that is needed from member countries to complete the assessment. Unfortunately the collection seems to not have been well focussed and a number of assumptions have had to be made. Limited time to complete a first version of the study has meant that not much cross checking and sensitivity analysis has been possible, this may be due to the complexity of the task as a fully integrated approach to assessing development options for a complex system physical and social river basin such as the Mekong inevitably leads to simplifications.

Work began early to fill in data and knowledge gaps and consult with member countries and from a modelling perspective this was largely successful in terms of developing baseline models for an extended 24 year period. The uncertainty with the frequency analysis on the model outputs can be quantified and error/confidence bands drawn as shown below for flow at the Kratie station.

Although there is a clear uncertainty at higher return period events of 1:100 year above, the effect of these on flood damage calculation is not likely to be high and within reasonable band.

Of greater uncertainty is the estimate of flood damage relation especially when extrapolated into the future using economic data. In Cambodia and Vietnam work had already been done in analysing the present day condition for a reasonable sample of flood areas but for Thailand and Lao very little previous analysis was available within MRC or supplied by the member countries,

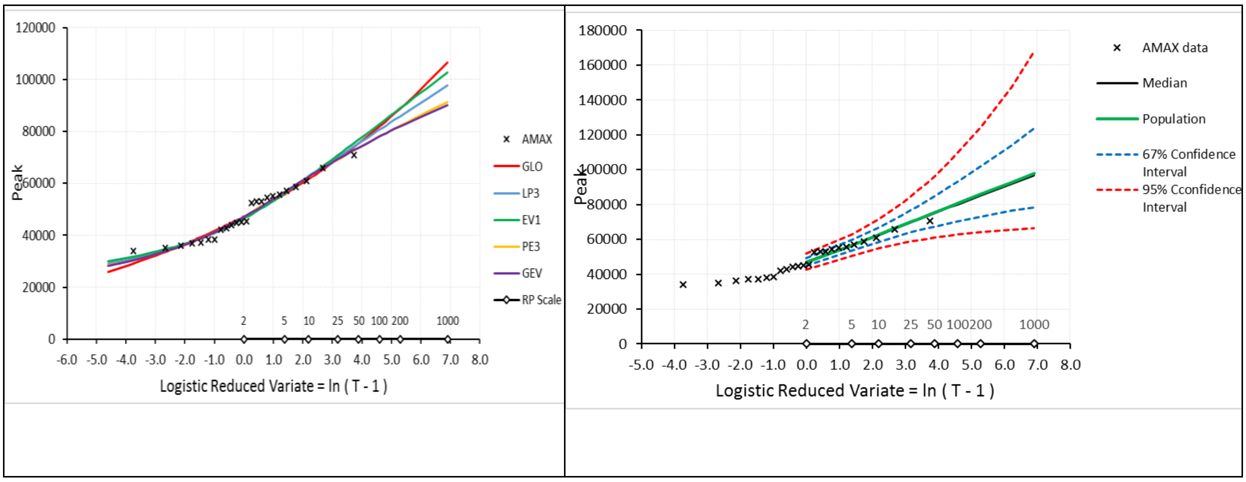


Figure 5-1 (a) Uncertainties connected with fitting of frequency distributions to model time series data. The chosen distribution used is Log Pearson III which is a central estimate of peak floods comparing with other distributions. b) Confidence bands for extending the estimates of return period event beyond the length of record

Within the model results the effect of the storage dams on flood frequency is apparent but in reality this depends on the operating rules followed. Within the models the assumptions of maximising hydropower production are reasonable but other factors such as the varying demand for energy during the year may affect the choices made by operators and there may be more or less storage available for flood mitigation. This is an uncertainty that could be reduced through better knowledge and understanding of the actual dam operations for current dams as well as though proposed.

The study has used the historic flood damage data to derive a method to calculate flood damage for different scenarios based on the changing water levels. This does not depend on flood mapping which is highly dependent on the available DEM so to some extent the uncertainties have been reduced but the so called ‘top down’ approach to flood risk/damage estimation has introduced more uncertainty into the projection of the future conditions for scenarios. It is believed that this uncertainty is a limitation on the confidence in absolute results in terms of cost effectiveness of flood protection but is appropriate for a preliminary appraisal of the issues.

The impact of the severe reduction in sediments on bank erosion has been interpreted based on the experience of other basins and there is currently no modelling available to indicate the time frame for the requirements of bank protection and the likely movement of the erosion wave downstream. Together with the limited initial study of the coastal erosion issue this is a significant limitation on the conclusions that can be confidently drawn and the costings entered into the economic analysis. The lack of any agreed data on sediment mining also meant that this could not be studied whereas the removal of sand from the river system is known to be significant. The conclusions regarding the erosion issue are thus more uncertain than the flood protection requirements and a limitation on the ability to estimate the cost of works for any cost benefit analysis.

The impact of a medium climate change scenario has been including in the main scenario and sensitivity testing for climate sub scenarios. The calculation of flood damage varies considerably but the conclusions for the Council Study do not seem highly sensitive to the climate assumptions chosen.

6 Conclusions

6.1 Assessment findings

Data has been collected from member countries on historic flood damages and this has been used to calibrate the flood damage calculator for Agricultural (rural) and Other (Urban and Infrastructure as well as indirect impacts). Results from this study show clearly how flood risks will increase significantly with time unless action is taken to raise the standard of flood protection where the risk is greatest. Those flood risks have been translated into flood damages within the assessment corridor for the main and flood scenarios considered by the Council Study.

It is recognised within the analysis that there are components of flood impact that will change relatively going into the future and thus should be separated in the analysis;

1. Flood Damage to Agriculture
2. Flood Damage to Infrastructure, including roads, banks, irrigation and government facilities including schools and health
3. Damage and loss to Private and Commercial Properties and their contents
4. Indirect Impacts such as the cost of relief measures, impact on health or loss of factory production

Under the previous studies an approach has been developed where damage components 2-4 are grouped together inter two relationships for predicting damage at a district level using statistics of the peak local water levels observed and in the scenario models. The data collected and available was for the key Cambodia Vietnam transboundary area and thus this more detailed data was used and scaled up to estimates of the full corridor for relevant scenarios. For Thailand and Lao PDR the technique has not yet been established so a more simplified approach was adopted using a representative relation between annual damages and flood return period.

A further significant effect considered was the large increase in urbanisation, development and the increasing value of assets at risk going forward into the future due more affluent societies. Previous studies have established this as a major factor and thus future change in flood damage should consider:

a) Change in flood risk due to hydrological changes due to infrastructure and climate

b) Change in flood risk due to socioeconomic change

The results for the main flooding areas of Cambodia and Vietnam are shown in Tables S1 and S2

The Council Study is being undertaken in parallel to the Flood Management team's 'Initial Studies of Climate Change Impact on flood regime' and both studies are benefitting from the different emphasis. Initial Studies are focussed on floodplain development and climate change whereas the Council Study is a more holistic study of multiple sectoral changes. The impact of floodplain development including urbanisation, irrigation and flood protection is to increase flood levels elsewhere and the findings of 'Initial Studies' are expected to result in more concrete recommendations for floodplain management than possible from this study. Damages are given in million $ either as an annual average (calculated probabilistically) or for the extreme event. Figures without flood defence Improvement are given as well as with flood defences with a 1:100 year level of protection in urban areas and 1:10 year for agriculture and rural areas.

For the main Scenarios result it can be seen in Table 1-1 that annual average flood damages in the Cambodia part of the assessment corridor could rise from around $9m to $53m allowing for climate change to 2040. With defences this could be reduced close to the current value on average though an extreme event that overtopped defences could cause $300-500m of flood damage.

Table 6-1 Flood Risk Damage by Scenario for CS Corridor in Cambodia

Corridor Cambodia		Socio economic Development	Water Infrastructure	Annual Average Damage ($m)			AAD Defences AG 10yr Prop 100 year	($m) Event damage in Extreme Flood
		Year	Year	Agriculture	Other&Urban	Total	With Defenses	1:100yr+
Scenario M1		2010	2007	4.6	4.1	8.7	2.6	21.3
Scenario M1		2040	2007	6.4	34.4	40.9	3.5	213.6
Scenario M2		2010	2020	2.8	2.6	5.4	1.6	10.2
Scenario M2		2040	2020	3.9	21.6	25.5	2.1	109.8
Scenario M3		2010	2020	2.8	2.6	5.4	1.6	10.5
Scenario M3		2040	2040	3.9	21.7	25.6	2.2	113.0
Scenario M3 CC		2010	2040	6.5	5.3	11.8	4.1	31.7
Scenario M3 CC		2040	2040	9.1	44.0	53.1	5.5	325.0
Scenario C2		2010	2040	14.4	14.1	28.5	7.0	117.1
Scenario C2		2040	2040	20.0	118.2	138.2	9.3	557.2
Scenario F1		2010	2040	8.9	7.2	16.1	4.5	75.7
Scenario F1		2040	2040	12.4	60.1	72.4	6.0	325.0
Scenario F2		2010	2040	3.8	0.6	4.5	Already	75.7
Scenario F2		2040	2040	5.3	0.7	6.0	Already	329.7
Scenario F3		2010	2040	16.8	16.8	33.6	7.0	117.1
Scenario F3		2040	2040	23.4	$ 141.16	$ 164.52	9.3	557.2

Similarly for the Vietnam delta as shown in Table 1-2 there is potential for flood risks to rise rapidly but this could be avoided with better flood defences especially for urban areas. Once such defences are overcome though there is potential for over $3.3 billion damage in a single event.

Table 6-2 Flood Damage estimation for Vietnam Mekong Delta

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	With 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 M2	2010	2020	3.7	16.9	20.5	3.7	123
Scenario M2	2040	2020	3.5	162.0	165.5	24.7	1,178
Scenario M3	2010	2020	3.6	16.7	20.3	3.7	121
Scenario M3	2040	2040	3.5	160.6	164.1	24.6	1,171
Scenario M3 CC	2010	2040	9.9	38.8	48.7	4.1	322
Scenario M3 CC	2040	2040	9.5	373.2	382.7	68.1	3,187
Scenario C2	2010	2040	21.8	56.6	78.4	18.2	427
Scenario C2	2040	2040	20.9	544.1	565.0	76.7	3,377
Scenario F1	2010	2040	15.2	44.3	59.5	15.3	330
Scenario F1	2040	2040	14.6	425.9	440.5	72.9	3,187
Scenario F2	2010	2040	9.9	6.6	15.3	Already	335
Scenario F2	2040	2040	9.5	63.4	72.9	Already	3,314
Scenario F3	2010	2040	16.8	33.6	16.8	18.2	427
Scenario F3	2040	2040	21.7	567.6	589.4	76.7	3,377

Changes in the sediment regime threaten the stability of the river banks and without intervention extensive bank erosion is predicted. To counter large scale erosion and loss of infrastructure additional costs will need to be incurred to manage and reduce loss of land and assets due to river bank collapses. The rate at which bank protective works will be needed will depend on the sediment transport rates from upstream but given that all scenarios show significant reductions then once other works are constructed then the erosion can be expected to move rapidly down the system.

6.2 Changes in Flood Regime

The main and sub scenarios related to the flood sector have been analysed for change both for mean flow and for extremes through flood analysis of return periods up to and below 1:100 year events. There is a small decrease in flooding for the M2 and M3 scenarios but with climate change there is a significant increase in peak water levels, expected annual and peak event damages etc. The more extreme C2 Climate Change scenario more than doubles the flood risk in Cambodia and Vietnam. Allowing for Socioeconomic change results in a significant increase in assets at risk and associated infrastructure/property and indirect damages that by 2040 will outweigh the agricultural loss.

6.3 Effect of Mainstream Dams

The storage within mainstream dams is small compared to the high flood volumes and thus the impact of mainstream dams on flooding downstream is very small. The scenario results for M2 and M3 indicate expected small reductions in flood risk in Cambodia and Vietnam especially though this is more than offset by climate change and sea level rise.

The possible local impacts upstream of mainstream dams in the backwater areas need to be considered on a case by case basis but is limited at high floods and if found to an issue then mitigation measured would be adopted. A more significant effect may occur due to releases of flow at critical times, again this has not been assessed but could be studied further in the available models. The flood management using dams scenarios F3 was unsuccessful and gave a small increase in flood risk showing that the responses of multiple cascade systems within the basin in the future will be a challenge to coordinate and further study is needed to prepare for emergency drawdown eventualities.

The impact of mainstream dams on sediment regime and hence potential bank erosion downstream is significant as the mainstream dams play a significant role in the deprivation of sediment load downstream. Ulltimately there is little doubt that the expected reductions in sediment load due to Upper basin dams and tributaries will necessitate significant expenditure on bank protection in Cambodia and the Vietnam delta in particular where over 300km of bank is at risk in the main Mekong and its six delta arms.

6.4 Development on the Floodplain

Loss of floodplain has been shown to raise peak flood levels and many urban and rural assets are already exposed to comparatively high risk of increasing damages. Combined with climate change, it is essential that the requirement for flood defences of certain areas is considered strategically, ensuring that steps to manage the essential functioning of the floodplain are set into land use planning and development control. Future Socioeconomic Development is already resulting in development pressures on the floodplain and steps to protect essential services of storage and conveyance are needed at the earliest opportunity. Additionally the impact of rising sea level will impact on flooding in the Vietnam delta. The Council Study considers only a short horizon to 2040 and without doubt sea level rise and climate change will continue to build with progressively higher impacts after this time period.

6.4.1 Flood Damages will increase substantially as countries develop and more assets are at risk.

Future Flood Damages will rise rapidly due to climate change and development putting more assets at risk. This can be offset substantially through sensitive flood protection works at the areas of most risk. At present much of the impact corridor is dominated by the potential risk of agricultural losses due to flooding. These risks will rise is time with the increased agricultural productivity also with developing economies there will be larger increase in assets at risk especially in urban areas. Increases in risk and thus potential losses may be a factor of 3 to 5 higher than current day. Mapping and prioritisation of a reduction in flood risk is needed. Measures and policies for the expected standard of service for urban areas and crops in particular are needed as is clear planning guidance for flood risk when developing infrastructure.

6.4.2 Transboundary Erosion Issues will increase rapidly with completion of dams in the LMB

An erosion problem along the whole of the Lower Mekong is steadily developing and will accelerate quickly once the planned dams are put in place. It is estimated that there is around 3450km of bank at risk along the mainstream channels, nearly 1400km within the Mekong Delta. It can be envisaged that bank protection works will be needed along the alluvial reaches of the main river. Further modelling work is needed to define how quickly the erosion will occur, but it is likely to be progressive as dams are developed and be realised within decades after completion. As the banks are developed the erosion will move downstream more quickly due to the 'hungry' river effect of rapid bed erosion causing degradation, followed by erosion of banks and lateral instability. With major infrastructure along the river as well as areas of international border between Lao and Thailand there is already a significant length of bank protective work in place on the Thai side of the river and increasingly on the Lao side. Further protection is will require substantial investment to contain the problem, estimated at around $6 billion.

The rate at which these bank protection works will be needed will depend on the mitigation measures adopted at the mainstream dams and how rapidly other bank protection works are developed upstream. The upstream bank protection is significant as it further starves the downstream reaches of sediments that might have been liberated by erosion. Major rivers such as the Mississippi are known to be still adjusting to changes over 100 years earlier though rapid change can also be expected as evidenced by the increasing loss of banks in the Vietnam delta following the major loss of sediments from the Upper Riparian catchment in 2010/11.

6.4.3 Biological Resources

There are positive impacts of flooding that must be incorporated into cost benefit assessments as well as flood damages. The BioRA Assessment shows changes mainly relative to the effect of dam development but for areas that will be behind flood defences in the future a loss of biological resource is also predicted. Further work is needed to be able to compare this expected loss with the benefit of flood protection which is shown to be high in the F2 scenario.

6.5 RECOMMENDATIONS

The modelling of flood extent and duration within the Mekong has been established since 2004 using the DSF models. The technique used is to simulate a long time series of 24 years and analyse specific years of extreme events or the statistics of the time period. Whilst the time period is reasonably long it is still short for estimation of 1:100 extreme floods and should be extended.

The modelling of scenarios also shows where some improvements are needed in particularly for operation of dams (F3 actually increased flood risk rather than decreasing it as expected). The areas behind flood protection works currently and in the future are also not well represented and more information is needed on banks etc to model this better.

The application of the WUPFIN tools for assessment of flood impact on agriculture is novel but as yet unproven against measured data (the predicted output of grain barly changes in flood years whereas member countries report major crop losses for big floods) and thus reliance should be placed on estimated damages using proven techniques as presented here until the impact modelling is improved.

The modelling of bank erosion downstream of dams needs to be done to assess how quickly bank erosion protective works are needed.

The data from member countries available for the council study team on future plans for floodplain development and flood protection is sparse and further work needs to be done to get a clearer picture of what should be included in the model.

The technique for damage estimation depends on collection of data for district level along the corridor for a range of events. Only a sample of districts provide sufficient detail to use this approach. Other approaches may be explored in the future including use of mapping of flood depth and use of depth damage functions related to asset value.

The future socioeconomic development has a significant impact on the flood damage results obtained and further consideration of this is needed.

Appendix A Current status of the flood protection and floodplain infrastructure thematic area

In this section an overview is provided on the flood damage in the LMB and especially attention is given to the larger flood events in the year 2000 and 2011. In addition, the approach for flood damage assessment as applied in the FMMP Component 2 Study (2010) and in the Initial Studies is described.

A1.1. Flood damage and losses – 2000 and 2011 compared

The flood conditions that prevailed in 2000, particularly over the Cambodian floodplain and the Mekong Delta, are generally acknowledged to have caused the greatest levels of total damage and loss documented since systematic assessments began in the 1980's. The 2000 floods affected all four countries in the Mekong River Basin - Cambodia, Lao PDR, Thailand and Viet Nam. According to the Mekong River Commission, however, Cambodia suffered the most severe effects of the floods with 43% of the total number of deaths recorded and 40% of the estimated damage.

The Royal Government of Cambodia (RGC) stated that the 2000 floods were the worst in more than 70 years and caused damage to infrastructure and livestock, population displacement, food shortages and disease. A report, compiled by the National Committee for Disaster Management (NCDM) in November 2000, put the death toll at 347 (80 percent of whom were children). Of the 750 600 households affected, comprising almost 3.5 million people, equivalent to over 25% of the national population, about 85 000 families had to be temporarily evacuated from their homes to safe areas.

Other statistics released by the RGC indicated that the agricultural and infrastructure losses were:

- Rice crop destroyed 374,100 ha
- Other crops destroyed 47,460 ha
- 988 schools affected (7,000 classrooms damaged)
- 158 health centers and hospitals damaged
- Almost 318 000 houses were damaged
- Over 7 000 houses destroyed.

Based on the NCDM report, the Council of Ministers estimated the total physical and direct damage at US$ 157-161 million.

In the Delta in Vietnam there were a reported 319 fatalities of whom almost 240 were children. Severe flash flooding across the Khorat Plateau in NE Thailand caused 25 deaths and in the Northern and Eastern Highlands of Lao PDR 15. In the Delta total economic losses were estimated to have been US$ 125.5 million.

The public health situation following the floods was precarious. The overcrowded and unsanitary conditions in safe areas raised fears of major waterborne epidemics, such as cholera or acute diarrhea. The loss of life due to water borne disease was a major factor that explains why juveniles accounted for by far the greater proportion of the flood related fatalities. In the post-emergency phase therefore the focus was to be on preventative health activities; specifically water and sanitation, the prevention of flood associated diseases and health education to affected populations.

The estimation of flood damage and losses in economic terms is difficult, as it is with other geophysical hazards such as droughts and earthquakes. Different sources can reveal substantial disparities. In the overview that follows it are the relative figures that provide the focus of interest rather than the absolute values, which are drawn from a wide spectrum of MRC and other documents and reports. A key observation is that within the Lower Mekong Region as a whole damage and loss is fundamentally a rural issue. The major towns and cities, such as Vientiane, Phnom Penh and those in the Delta are protected by engineering works, whereas rural areas are not. As a consequence they are the most exposed, with agricultural damage and losses in terms of local domestic property, schools and clinics at the forefront.

The image below confirms this perspective. It shows the flood inundation local to Phnom Penh on 15 October 2011. The city itself is largely free from flooding but to the east and along the Bassac River there is widespread inundation.

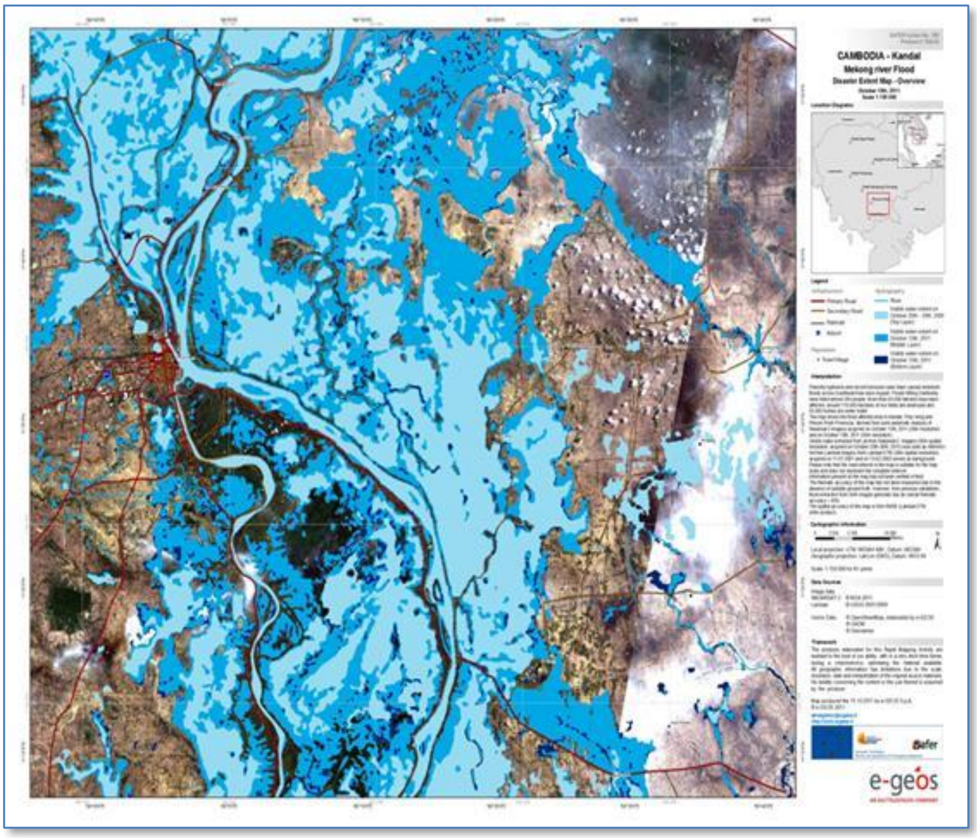


Figure A.6-1 The flood situation local to Phnom Penh on 15 October 2011. The city itself is largely free from inundation, but the unprotected rural areas to the east and south reveal widespread flooding.

Table A 6-3 2011 Flood – fatalities and damage within the Mekong Basin in each of the four riparian countries.*(na = not available at MRCS)*

Country	Deaths	Property units affected	Property units damaged	Schools affected	Rice crop lost or damaged (ha)	Other crops lost or damaged (ha)
Cambodia	250	268 600	13 000	1 360	267 000	17 300
Lao PDR	42	-	82 500	250	77 000	-
Thailand	na	na	na	na	na	na
Viet Nam Delta	89		176 000	1 260	250 000	-
Viet Nam Mekong highlands	15		85 000	-	3 300	-

With these considerations in mind, Table A **6-3** reveals the 2011 flood fatalities and damage that occurred in each of the riparian countries during 2011. The geography of the event, in that it was largely confined to areas downstream of the Se Kong, Se San and Srepok tributary system from which most of the flood water originated, means that Cambodia and the Delta suffered by far the most. Of the recorded fatalities 85% occurred here, with 63% in Cambodia alone. The damage estimates are dominated by losses in the same areas of the Basin. In Thailand no excessive flooding occurred in 2011 in the LMB part and also no fatalities and damage were recorded for the LMB part.

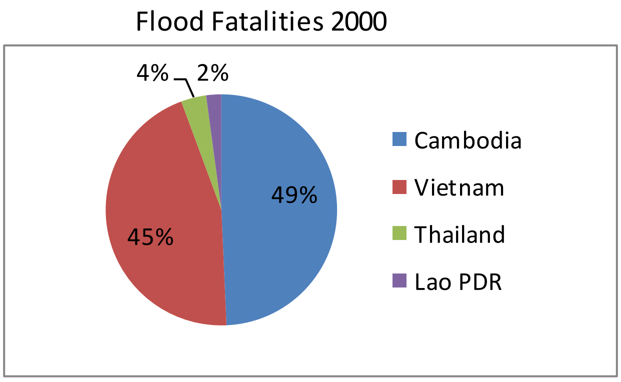
A comparison between the 2000 and 2011 floods (Table 2-2) shows a repeat of this pattern.

Table A 6-4 Preliminary comparison of fatalities and economic damage between the 2000 and 2011 flood events in the Lower Mekong Basin.

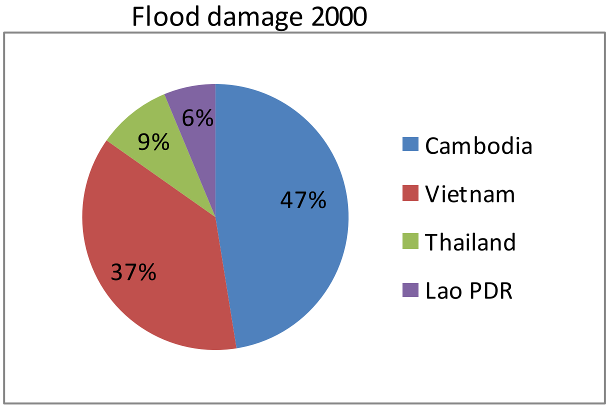
Country	2000 Flood		2011 Flood	
	Fatalities	Economic damage (million US$)	Fatalities	Economic damage (million US$)
Cambodia	350	157 - 161	250	634
Lao PDR	15	30	42	208
Thailand	25	21	*	9.7*
Viet Nam	320	125	104	260

In terms of fatalities almost 90% occurred in Viet Nam and Cambodia while they also accounted for more than 80% of total regional economic damage and loss according to the estimates (Figure A2-2 and 2-3).*Thai economic damage in 2011 as recorded in provinces within CS impact zone only.

Figure A6-2 Flood fatalities and damage in the Lower Mekong Basin by riparian country in 2001.

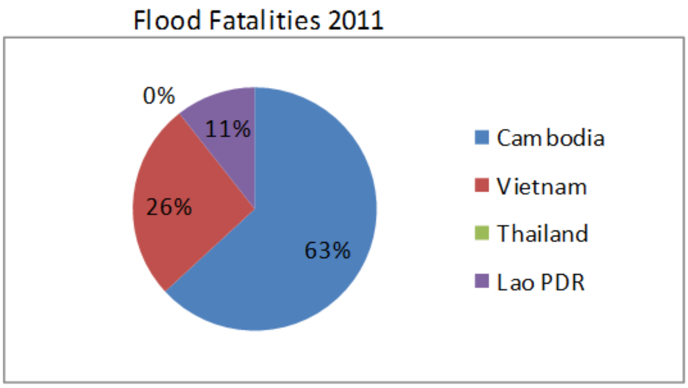


Country	Number	% total
Cambodia	350	49%
Vietnam	320	45%
Thailand	25	4%
Lao PDR	15	2%
Total	710	100%

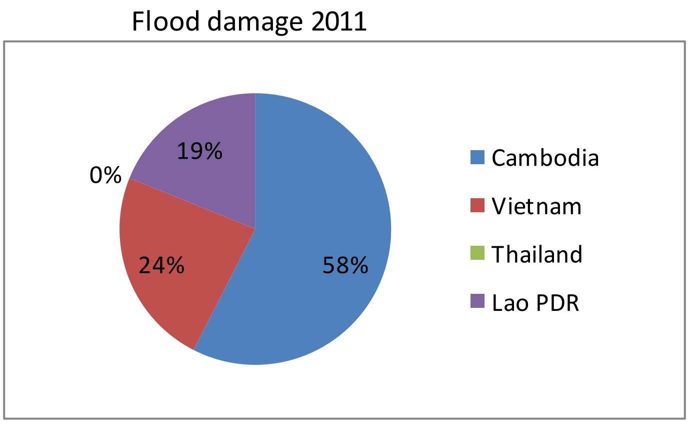


Country	Total losses Millions U$	% total
Cambodia	159	47%
Vietnam	125	37%
Thailand	30	9%
Lao PDR	21	6%
Total	335	100%

Figure A6-3 Flood fatalities and damage (millions of US $) in the Lower Mekong Basin by riparian country in 2011.



Country	Number	% total
Cambodia	250	63%
Vietnam	104	26%
Thailand	n.a.	#VALUE!
Lao PDR	42	11%
Total	396	100%



Country	Total losses Millions U$	% total
Cambodia	634	58%
Vietnam	260	24%
Thailand	n.a	#VALUE!
Lao PDR	208	19%
Total	1102	100%

These results clearly reveal the vulnerability of the Cambodian floodplain and the Mekong Delta to the regional flood hazard and its impacts. The reasons are largely demographic. Here are the highest regional population densities, attracted in the main by the agricultural potential of the floodplain and deltaic soils. This is not to say that floods and flooding in NE Thailand and Lao PDR are inconsequential in comparative terms. It is simply that the scale of impacts is much less.

Floods and flooding over the greater part of the Cambodian floodplain and the Mekong Delta are the result of hydrological factors in the form of critically high water levels in the Mekong mainstream.

Over the greater part of Lao PDR and the Thai Mekong region, remote from the Mekong itself, floods and flooding are the result of meteorological conditions resulting in more local flash flooding and storm induced inundation when drainage infrastructure cannot cope.

In other words, meteorological factors are either direct or indirect. Tropical depressions and typhoons cause high water levels in the Mekong resulting in flooding. Or extreme storm rainfall is the primary cause of flooding elsewhere. In effect the direct cause of floods is either hydrological or meteorological.

Upstream of the Cambodian floodplain in Lao PDR and Thailand there are areas adjacent to the mainstream that are susceptible to overbank flooding but these are nowhere near as extensive as those further downstream. One of the principal effects that exacerbates the extent of flooding in these upstream zones is that high water levels in the mainstream causes significant backwater effects in the large left bank tributaries in Lao and in the Mun-Chi Basin in Thailand, thus extending the flooding laterally.

Flood damage and losses period 2000 – 2009

For the period 2000- 2009 the various AMFR reports provide details for the flood damage. The results are listed in the tables 2-3 (Thailand), table 2-4 (Lao PDR), table 2-5 (Cambodia) and 2-6 (Vietnam) hereunder.

In the table for Thailand the flood damage is listed for the whole country; damage in Mekong Basin is limited compared with the damage for the whole Thailand. The relevant districts affected by Mekong flooding are Meung Chiang Rai and Chiang Saen districts. In annex 3 details for flood damage for these districts are given.

In the table for Lao PDR only three years are listed 2006, 2007 and 2008. The years 2007 and 2008 show considerable losses.

In the table for Cambodia the year 2000 shows a severe flood while other years such as 2001 and 2004 are less severe but still show considerable damage. In the other years the flood damage is limited.

The table for Vietnam shows that the floods in 2006, 2007 and 2008 much less severe than the very severe flood in 2000.

Table A1-3 Thailand: Flood damage compared to those of recent years (extracted from AMFR 2008)

Descriptions		2008	2007	2006	2005	2004	2003
Areas	Provinces	65	46	47	63	59	66
	Districts	584	486	482	541	337	349
	Villages	22,874	20,499	20,625	10,326	9,964	5,281
Human	People	4,494,187	3,640,978	5,198,814	2,874,673	2,324,441	1,882,017
	Households	1,197,253	940,663	1,430,085	763,847	619,797	485,436

	Casualties	97	62	340	88	31	54
Assets	House	18,258	7,369	49,611	6,040	5,947	10,329
	Fish ponds	42,424	34,767	125,683	13,664	12,884	22,339
	Live stock	504,737	38,079	142,211	696,123	71,889	301,343
	Agriculture field (rai)	3,023,477	2,645,982	5,605,559	1,701,450	3,298,733	1,595,557
Infrastructures	Roads	12,133	8,330	10,391	5,697	4,173	5,071
	Bridges	573	309	671	667	173	393
	Hydraulic structures	595	591	778	22,527	716	179
	Institute buildings	197	271	1,425	2,123	827	174
	Drains	561	163	1,085	1,482	594	282
US$ million		72	48	202	170	24	58

These figures are for the country as a whole. Of the US$72 million flood damage figure for 2008 about US$20 million occurred in the Thai Mekong region.

Table A6-4 Lao PDR: Flood damage assessment (extracted from AMFR 2006, 2007 and 2008)

Description	**2006**	**2007**	**2008**
Provinces affected	5 provinces (Luangnamtha, Attapeu, Xekong, Saravane, and Champasack)	4 provinces	4 provinces (Luangprabang, Vientiane Capital, Bolikhamxay and Khammuane)
Districts affected	20	27	26
Villages affected	404	614	664
Houses affected	13,549 (21 houses and 17 rice stock swept away)	25,292	32,610
People affected	89,849 persons	118,074 persons in Khammouane, Savannakhet and Saravane provinces	95,158 persons in Bolikhamxy and Khammuane provinces
People killed	5	2 persons died	3
Agriculture			
Hectares of Rice and other Crop damaged	6,913.22	256,778	28,516.67
Hectares of Industry log damaged			53.54
Hectares of vegetable fields		490.62 (of 1,384.03 planted area)	
Kilogram of seed bed / nursery			860
Livestock			
Cattle	298 head (buffalos, cows, and pigs) lost	343 (buffalos, cows, pigs and goats)	702 head (buffalos, cows, pigs and goats) lost
Poultry	5,912 head lost	74,980 head lost	995 head lost
Fish ponds, aquaculture and	168 sites and 98.2 ha damaged	136 sites and about 1,000,000	44 sites fish ponds 355.59 ha

Mekong fish net		fish damaged	aquaculture and 71 sites of Mekong fish net damaged
Infrastructure			
Schools	13 sites affected	11 primary schools inundated	63 sites affected
Health Center	3 sites affected	2 health centers affected	3 health centre of Hinboun village affected and 50 sites and medicine cabinets
Bridges damage	2 (in Xekong and Attapeu provinces)		3 sites
Erosion along the Mekong river			18 sites destroyed 27 kilometres of length
Road damage		60-70 meters length of road at 3 locations	40 places damaged 314.38 kilometres of length
Canal systems damaged	8 km		48 sites
Irrigation	259 sites. Damages to reinforce concrete, masonry weirs, gabions and traditional earth weirs	29 sites affected (23 sites damaged)	
Headworks damage	20		
Drainage tubes affected			53 metres
Water wells damage			929 sites
Underground water well damage			812 sites
Natural water spring damage			1 site
Villagers toilets affected			4,954 sites
Temple		2 temples affected	
Market	Namtha market inundated with 0.6 m depth	Mahaxay District market affected	
Boat	21 damaged or lost	27 boats swept away by strong flow	
Total Flood Damage (US$)	3.1 million	NA	56 million

Table A6-5 Cambodia: Flood Damage Assessment (extracted from AMFR 2008)

Year	Total Flood Damage (US$)	Major area affected	Type of flood	Major components of loss
1996	86,500,000	Along Mekong, Bassac and around Tonle Sap Lake	Mekong flood and flash flood	Crops (250,218 ha), Livestock (327) Houses (3,768), Schools (173) Roads (802 km), Bridges (290 sites) Culverts (2,499 sites), Dams (65 sites) Dead (169 persons)
2000	161,000,000	Along Mekong, Bassac and around Tonle Sap Lake	Mekong flood and flash flood	Crop s(421,568 ha), Houses (7,086) Schools (6,620), Roads (908,710 km) Bridges (1,856 km), Culverts (17 sites) Dams (397 sites), Dead (347 persons)
2001	36,000,000	Along Mekong, Bassac and around Tonle Sap Lake	Mekong flood and flash flood	Crops (164,173 ha), Houses (2,251) Schools (911), Roads (7,976 km) Bridge s(175 sites), Culverts (44 sites) Dams (201 sites), Livestock (956) Dead (62 persons)
2002	12,450,000	Along Mekong, Bassac and around Tonle Sap Lake	Mekong flood and flash flood	Crops (45,003 ha), Houses (35) Schools (2), Health centre (7) Roads (12 km), Dams (201 sites) Livestock (956)
2004	55,000,000	Along Mekong, Bassac and around Tonle Sap Lake	Mekong flood and flash flood	Crop (247,393 ha)
2005	3,810,000	Along Mekong, Bassac and around Tonle Sap Lake	Mekong flood and flash flood	Crops (1,500 ha), Houses (1,700 flooded, 32 collapse), Schools (30 flooded), Dead (4 persons)
2006	11,800,000	Along Mekong, Bassac and around Tonle Sap Lake	Mekong flood and flash flood	Crops (13,787 ha), Roads (70 km) Dams (41 sites), Bridges (24 sites)

				Dead (11 persons),
2007	9,000,000	Along Mekong, Bassac and around Tonle Sap Lake	Flash flood	Crops 18,786 ha, Houses 11 Roads 34 km
2008	5,750,000		Flash flood	Crop 18,907

Table A6-6 Vietnam: Flood damage (extracted from AMFR 2007 and 2008)

Mekong Delta

Description	Flood impacts 2006	Flood impacts 2007	Flood impacts 2008 *	Flood impacts 2000
Number of affected provinces	5	5	5	13
Number of affected families	15,530	13,500	0	800 000
Number affected people	77,650	67,500	0	10 million
Number of people killed	42	30	7	453
Rice & upland crop damaged (ha)	15,223	14,688	68	2.0 million
Total estimated cost (US$ million)	2.00	1.50	*	250

Central Highlands

No.	1990	1994	1995	1996	1998	1999	2000	2002	2003	2006	2007	2008
People												
Killed	22	2	3	4		13	>20	2	6	0	29	6
Missing				5		41			2	0	4	1
Injured								1	1	0		
Houses												
Lost	22								7	5	166 d	
Inundated								1500			12,447	
Agriculture												
Lost		400								24	20,344	79
Inundated								9000	1000	126	24,393	
Fish ponds damaged											593	
Bridges												
Destroyed		32				10				1	59	8
Damaged											14	
Water containers												
Damaged		4									37	
Eroded											331,837	
Number of provinces effected	4	4	4	4	4	4	4	4	4	4	4	4
Total Cost (US$10 million)	0.5	1.0	n/a	n/a	n/a	0.2	n/a	3.0 .	0.5.	n/a	50.8	1.0

A1.2. Flood damage and losses period 2010 – 2014

In Table A1-7 the damages for years 2010 to 2014 are shown and it can be seen that the amount of damage varies greatly from year to year 2011 and 2013 being disastrous. The figures for the whole Thailand and Viet Nam are shown for comparison.

In 2013 the reported losses in Lao PDR and Thailand were 62 and 210 Million USD, respectively. They were the consequences of floods in tributaries during several tropical storms hitting the region.

Table A6-7 Average annual flash flood and river flood loss and damage in the Lower Mekong Basin 2010-2014 in Millions USD (Source: MRC National Flood Reports, MRC 2015, Desinventar.net).

	2010	2011	2012	2013	2014	Mean annual loss
Cambodia	N/A	634	N/A	356	N/A	-
Lao PDR	21	208	1.5	62	12	64
Thailand (LMB part)	47	N/A	N/A	210	6	88
Viet Nam, Delta	55	260	16	23	2.7	71
Viet Nam, C. Highlands	N/A	60	1	0.2	5.7	17

Inundation floods in the floodplains of Cambodia and in the Delta of Viet Nam cause a lot of damage when they happen, because these areas are densely populated and have much infrastructure. Also in Thailand and Lao PDR river inundation floods may cause huge damages, as in 2008, but in other years flash floods are the main cause of flood damage. However, in many cases it may be difficult in tributaries to make a strict distinction between river and flash floods.

Table 6-8 Average annual number of fatalities due to floods in the Lower Mekong Basin.

(Source: MRC National Flood Reports)

	2010	2011	2012	2013	2014	Total
Cambodia	8	250	26	168	49	501
Lao PDR	7	42	5	17	5	76
Thailand (LMB part)	N/A	N/A	N/A	17	4	
Viet Nam, Delta	78	104	38	35	12	267
Viet Nam, C. Highlands	N/A	15	0	45	17	77
Entire Thailand	79	655	5	80	4	1 200
Entire Viet Nam	238	265	N/A	285	133	230

In whole Viet Nam 250 flash floods have been recorded between 2000 and 2014, causing more than 600 fatalities and costing more than 150 Million USD (Viet Nam Annual Flood Report 2014). In the LMB part only areas in the Central Highlands experience flash floods, 77 fatalities were recorded here in the period 2010-2014.

In Cambodia there are some occurrences of flash floods but losses from inundation from the mainstream Mekong cause the most economical damages and fatalities. Since 2010 more than 500 fatalities has been reported in Cambodia. In Lao PDR and Thailand (Mekong part) the losses are mainly caused by flash floods, with 76 fatalities recorded in Lao PDR and 27 in Thailand during 2010 to 2014. In Table 2-8 a summary of fatalities in the 4 countries is presented.

Flash floods have a significant impact on the lives of people affected, causing loss of lives and inflicting damage on houses and infrastructure. Preparedness on flash floods is restricted to assessment the local risk in terms of soil saturation and forecasted rainfall intensity for the catchment, and to issue warnings to at least minimize the risk to people’s life.

A1.3. Results FMMP Component 2 study.

As part of the FMMP Component 2 Study flood damage estimation curves and flood risk has been calculated for the 59 districts in the Cambodian/Vietnam transboundary floodplain.

In short the approach applied in the Component 2 study is as follows:
There are basically two approaches for flood risk assessment[1]: Absolute approach (a topdown) and relative approach (a bottom-up). In the absolute approach historical damage data for an (administrative) area are used to assess the flood damage risk in that area. In the relative approach inundation-damage relationships are developed on a per unit (ha, % of house value) basis, and the flood damage risk is assessed by applying the per unit risk to the number of units in the concerned area.
In the Component 2 study, considering resource, time and data availability, absolute approach has been applied for flood damage assessment to Housing, Agriculture, and Infrastructure.
Housing damage covers individual houses, structures and properties of flood affected families.
Agriculture damage covers crops and aquaculture which is an important in lower Mekong Delta.
Infrastructure damage covers all remaining items such as public infrastructure and utilities, industries, institutions etc.
The grand total of damages caused by a flood in a certain district is the total of direct damages plus the total of indirect damages. Direct damages are obtained from local authorities at provincial and district levels from 2000-2008. It covers loss of life, damages to housing, crops, aquaculture, and infrastructure broken down into irrigation, transportation, power and water supply, education, health etc. The indirect-direct damage ratios were taken from results of the detail survey during the Stage 1 for the focal areas to estimate the grand total of damages.

A **first step** in this approach is the proper assessment of the flood hazard, i.e. the flood levels with different exceedance probabilities with the help of the MRC ISIS model.
The **second step** is to establish damage functions for three damage group categories with maximum flood water level for individual district.
The **third step** is to develop flood damage probability curves and hence calculating expected damage at selected flood return period of 100, 50, 25, 10 and 2 years.

A similar approach is proposed for the Council Study; an example of damage curve and flood risk is shown hereunder. In the framework of the Initial Studies these damage curves and flood risk calculations are updated to the existing situation 2014 and the flood risk is calculated for the future situations 2030, 2060 and 2090.

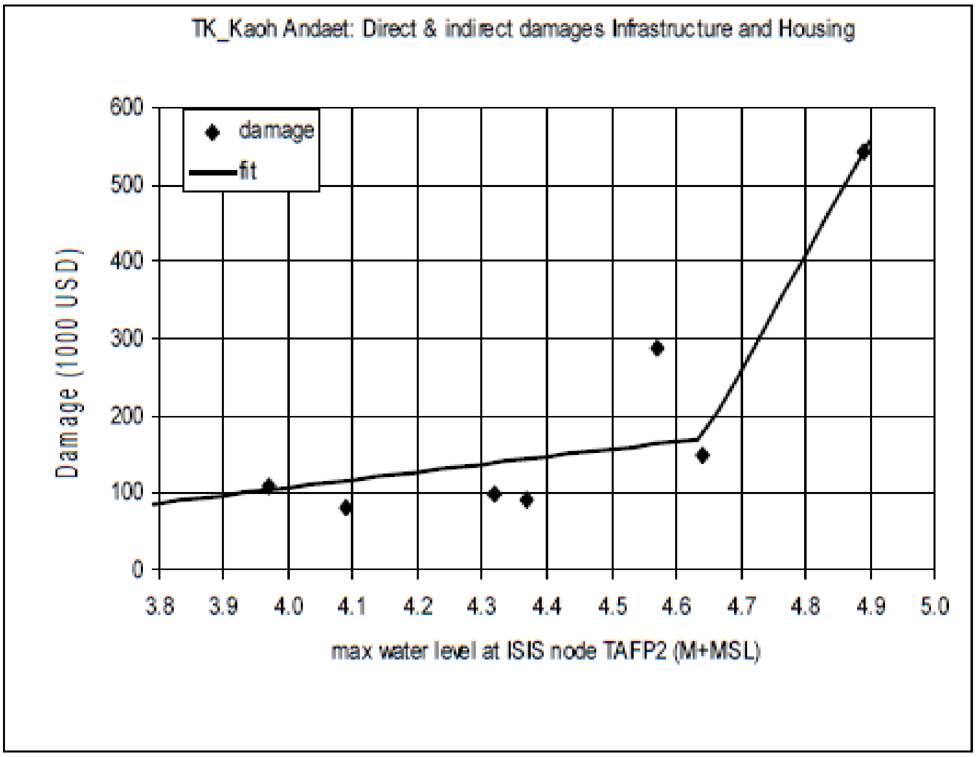


Fig 2-4: Flood damage estimation curve for Kaoh Andaet for Infrastructure and housing

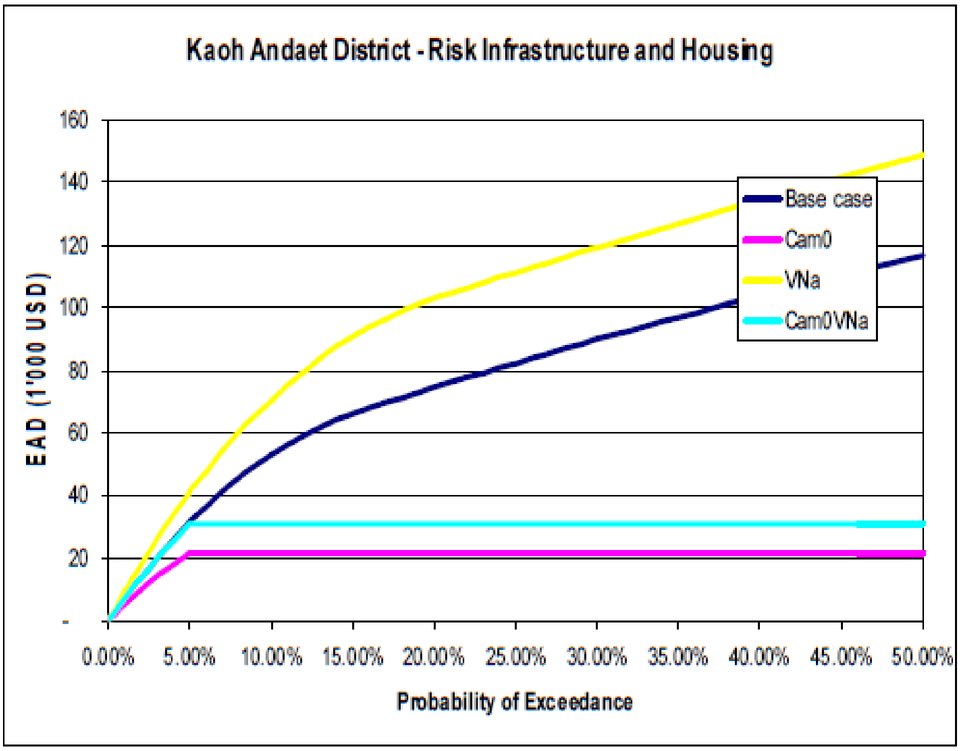
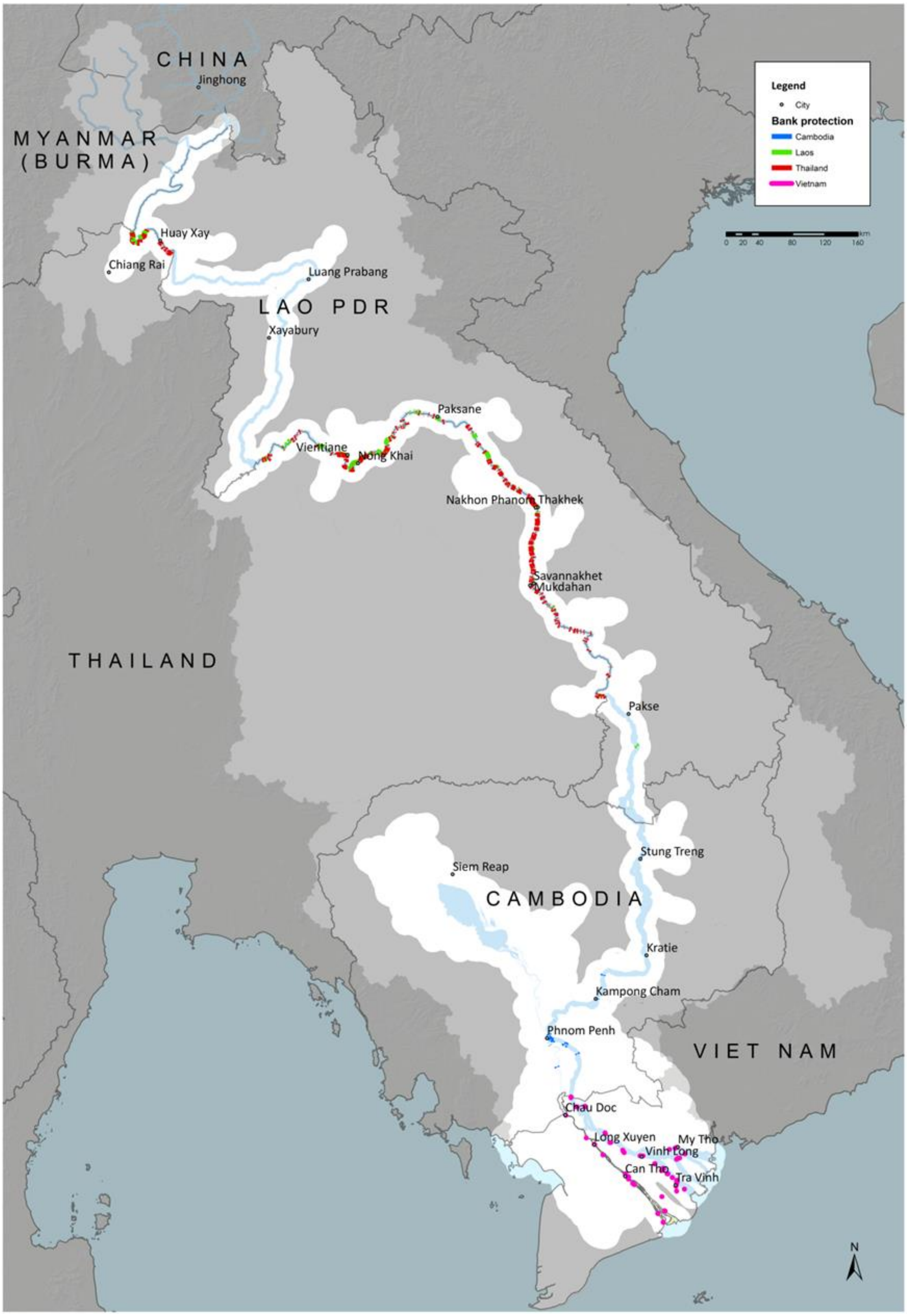


Fig 2-5: Flood risk calculation for Kaoh Andaet for Infrastructure and housing

Appendix B Bank Protection Works

Bank Protection Works are closely linked with flood defences and thus an estimate of the existing lengths of protection were made for the Council Study as shown below. Proportionally the length of bank with protection already constructed (2016) is much greater in the upper LMB of Lao and Thailand with little protected bank (as yet in Cambodia

Country	% of river length with bank protection in 2015
Laos	5.84%
Thailand	17%
Cambodia	1.71%
Vietnam	6.3%


CHINA
Jinghong
MYANMAR (BURMA)
Legend
City
Bank protection
Cambodia
Laos
Thailand
Vietnam
Huay Xay
Chiang Rai
Luang Prabang
LAO PDR
Xayabury
Paksane
Vientiane
Nong Khai
Nakhon Phanom
Thakhek
Savannakhet
Mukdahan
THAILAND
Pakse
Stung Treng
Siem Reap
CAMBODIA
Kratie
Kampong Cham
Phnom Penh
VIET NAM
Chau Doc
Long Xuyen
My Tho
Vinh Long
Can Tho
Tra Vinh
N

Appendix C Estimated Standards of Service Against Flooding of Existing Defences using data from MRC Flood Warning System.

The level of protection Standards of Service Against Flooding of Existing Defences are not well established but one source of information is to use the data from the MRC Flood Warning System. For most this varies between less than 5 year protection up to 50-100 year in some locations as shown below.

		Gauge station data					MASL flood recurrence interval (years)						water level flood recurrence interval (years)				
Urban area	Country	Gauge sta	Gauge sta	Zero gauge ab	Flood level	Flood level MASL	2	5	10	20	50	100	T>5	T>10	T>25	T>50	Return pe
Pakse	Laos	Pakse	PKS	86.490	12.00	98.49							13	13.2	13.3	13.8	<5
Luang Prabang	Laos	Luang Pral	LUA	267.195	18.00	285.20							17.5	18	20.3	21.3	10-25
Xayabury	Laos																
Savannakhet	Laos	Savannakh	SAV	125.022	13.00	138.02							11.9	12.2	13.1	13.2	10-25
Huay Xay	Laos																
Paksanh	Laos	Paksane	PAK	142.125	14.50	156.63							14.2	14.7	14.7	14.8	5-10
Vientiane	Laos	Vientiane	VIE	158.040	12.50	170.54							11.8	12.1	12.7	13.2	10-25
Thakhek	Laos	Thakhek	THA	129.629	13.50	143.13							13.8	14.3	14.6	14.7	<5
Stung Treng	Cambodia	StungTreng	STR	36.790	12.00	48.79							11.1	11.5	11.9	12	>50
Siem Reap	Cambodia																
Battambang	Cambodia																
Stung Saen	Cambodia																
Pursat	Cambodia																
Kratie	Cambodia	Kratie	KRA	-1.080	23.00	21.92							22.2	22.6	22.9	23	>50
Kampong Cham	Cambodia	Kompong (	KOM	-0.930	16.20	15.27							15.7	15.9	16.1	16.4	25-50
Prey Veng	Cambodia																
Phnom Penh	Cambodia	Phnom Pe	PPP	0.000	10.00	11.00	8.9	9.4	9.8	10.2	10.7	11.1	9.5	9.8	10	10.1	50-100
Prek Kdam	Cambodia	Prek Kdan	PRE	0.080	10.30	10.38							9.5	9.8	10	10.1	>50
Koh Khel	Cambodia	Koh Khel (	KOH	-1.000	12.00	11.00							7.7	7.8	7.9	8	>50
Neak Luong	Cambodia	Neak Luon	NEA	-0.330	8.00	7.67							7.8	7.9	8.1	8.2	<5
Long Xuyen	Vietnam																
Chau Doc	Vietnam	Chau Doc	CDO	0.001	3.50	3.50	3.8	4.3	4.5	4.6	4.7	4.9	4.6	4.4	4.6	4.9	<2
Cao Lanh	Vietnam																
My Tho	Vietnam																
Can Tho	Vietnam																
Tra Vinh	Vietnam																
Ha Tien	Vietnam																
Tan Chau	Vietnam	Tan Chau	TCH	0.001	4.2	4.20							4.7	4.8	4.9	5	<5
Ving Long	Vietnam																
Mukdahan	Thailand	Mukdahan	MUK	124.219	12.60	136.82							13	13.4	13.6	13.9	<5
Nakhon Phanom	Thailand	Nakhon Pl	NAK	130.961	12.70	143.66							12.5	12.8	13.2	13.3	5-10
Chiang Rai	Thailand																
Nong Khai	Thailand	Nongkhai	NON	153.648	12.20	165.85							12.4	12.8	13.5	13.9	<5
Chiang Saen	Thailand	Chiang Sa	CSA	357.110	11.80	368.91							9.4	9.8	10.8	12.3	25-50

Appendix D Data Collection - flood protection

1. Flood protection works in Lao PDR

The public investment in Lao PDR is planned for 5 years basic and disbursed on annual basic, it means that the public investment project is defined within these periods, the Government of Lao PDR is implementing its 7th National Socio-Economic Plan 2011-2015 and prepare for the 8th National Socio-Economic Development Plan 2016-2020, therefore, the flood protection works in this report are elaborated within these two periods.

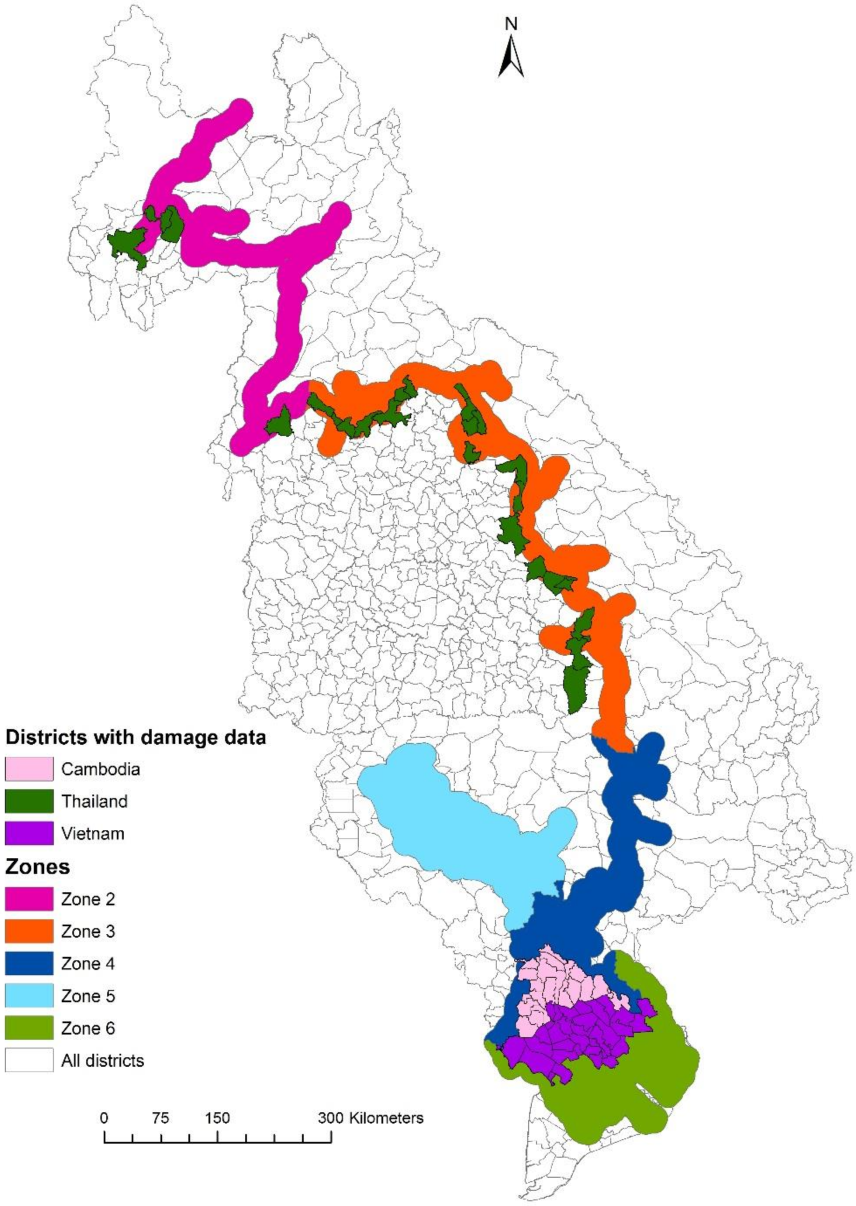
By 2015, the Government of Lao PDR has implemented several river bank protection projects covered more than 130,02 Km , 3 projects are associated with flood protection works which are : the construction of flood protection dike in the Municipality of Thathom district, river channel dredging in the Municipality of Sayabury province, the major river bank protection and flood proofing project in this period was the Korean funded Mekong River flood protection dike in Vientiane Capital covered 12.2 Km and feasibility study of national road No.11 improvement and 26,40 Km- flood protection dike in Vientiane Capital from Lao-Thai Friendship bridge to Houaymakhiew steam.

The Government of Lao PDR has set a milestones for the period between 2016-2020 to implement the construction of flood protection dike associated with river protection works in 11 priority provinces covers 35 Km including : Phongsaly province (Yod Ou District), Luangnamtha province (Luangnamtha district), Oudomsay province (Xai and Bang districts) , Luangprabang province (Luangprabang and Xiangngeun districts), Borikhamsay province (Thathom District) , Saysomboun province (Anouvong districts), Vientiane province (Thoulakhom district) , Khammouan Province (Nongbok district), Savanaket province (Kaisorn Phomvihanh and Saibury districts), Champasack province (Pakse district) , and Attapeu province (Samukisay district). Moreover, the national road No.11 improvement and 26, 40 Km- flood protection dike in Vientiane Capital from Lao-Thai Friendship Bridge to Houaymakhiew steam are proposed during this period.

Apart from the construction of flood protection dike in association with the river bank protection , the Government of Lao PDR is also implementing the flood protection works together with the irrigation development, there are 2 major projects which are being implemented since 2011, which are (1) Xebangfai-Xebanghieng Irrigation and Flood and Drought Management Project which is being implemented on the drainage - water gate No.3 of Namtheun 2 hydropower project and (2) GMS Flood and Drought Risk Management and Mitigation Project which are being implemented in Vientiane Capital

Conclusion

The flood protection work in Lao PDR is characterized by the river bank protection and irrigation and drainage, as the flood protection work is always associated with these activities , while the period between 2011-2015 showed that the major works were undertaken along the Mekong River , especially in Vientiane Capital , the period between 2016-2020 will keep focusing on Vientiane Capital and major cities along the Mekong River and its major tributaries like Xebangfai and Xebanghieng as they have high socio-economic importance.

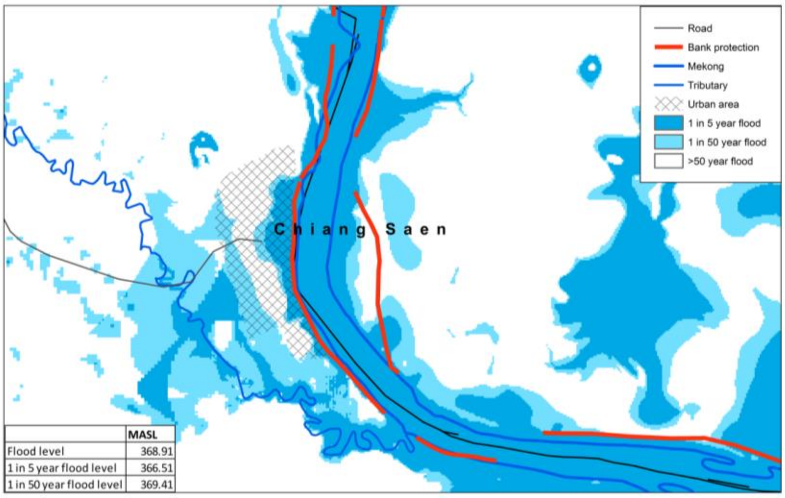


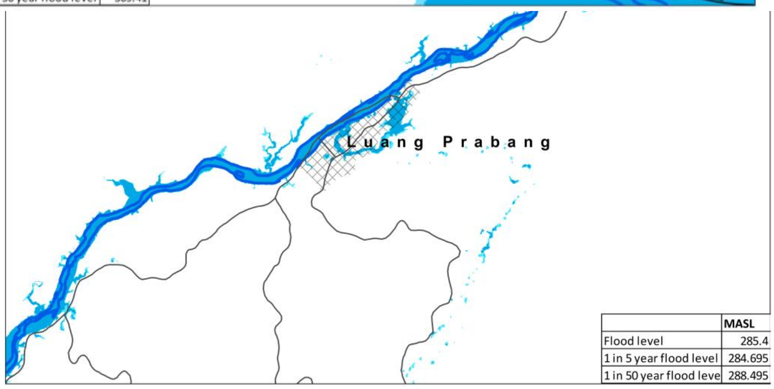
Flood Damage Data Provided by Vietnam for Council Study.

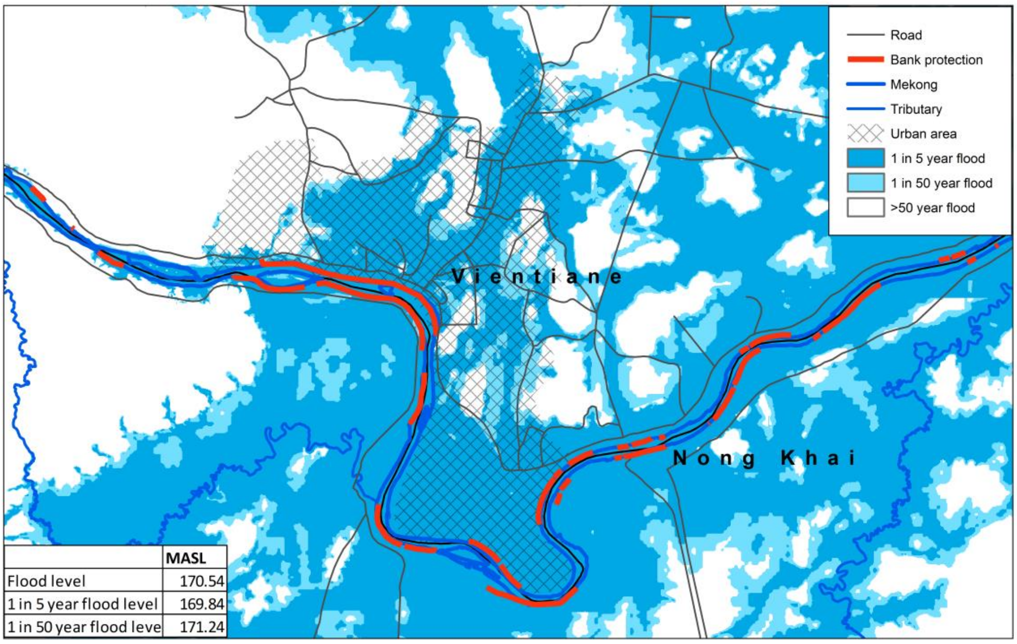
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Percentag
Long An															
Duc Hoa	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Ben Luc	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Thu Thua	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Can Duoc	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Can Giuoc	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Chau thanh la	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Tan Tru	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Tan An	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Kien Giang															
Giang Thanh	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Chau Thanh	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Giong Rieng	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Go Quao	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
An Bien	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
An Minh	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Vinh Thuan	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Phu Quoc	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Kien Hai	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
U Minh Thuong	n	n	n	n	n	n	n	y	y	y	y	y	y	y	50
Tien Giang															
Cai Lay	n	n	n	n	n	n	n	n	n	n	n	y	n	n	7.14
Tan Phuoc	n	n	n	n	n	n	n	n	n	n	n	y	n	n	7.14
Chau Thanh	n	n	n	n	n	n	n	n	n	n	n	y	n	n	7.14
My Tho	n	n	n	n	n	n	n	n	n	n	n	y	n	n	7.14
Vinh Long															
Binh Minh	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
Tam Binh	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
Long Ho	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
Vinh Long Provincial City	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
Mang Thit	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
Ben Tre															
Cho Lach	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
Ben Tre Provincial city	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
Can Tho															
Thot Not	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
O Mon	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
Can Tho City	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
Chau Thanh	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
Vinh Thanh	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0
Total															35.71

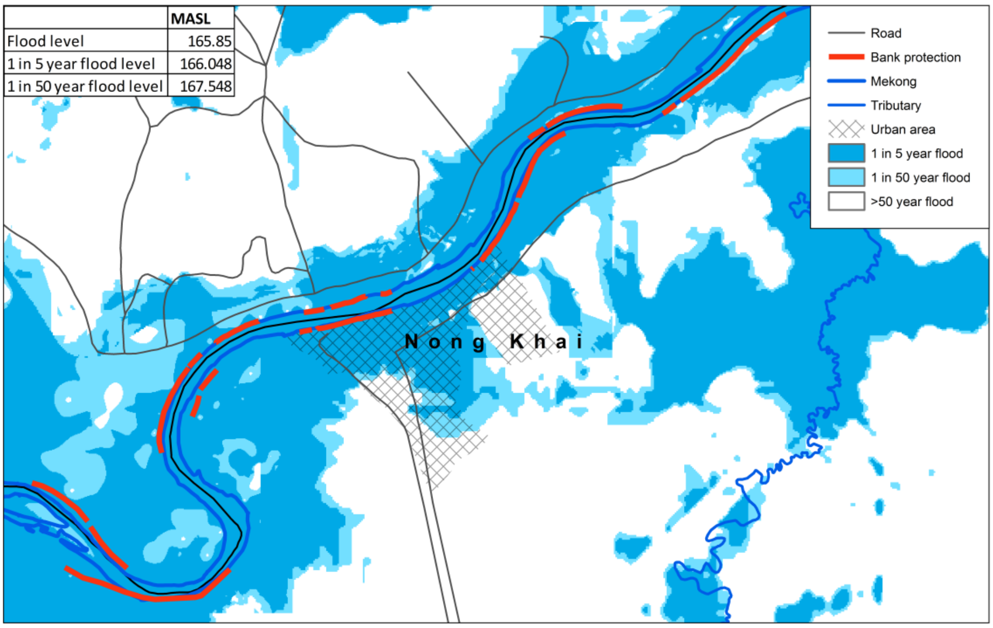
Appendix E Mapping of 'No Defences' Flood Extent for major urban centres.

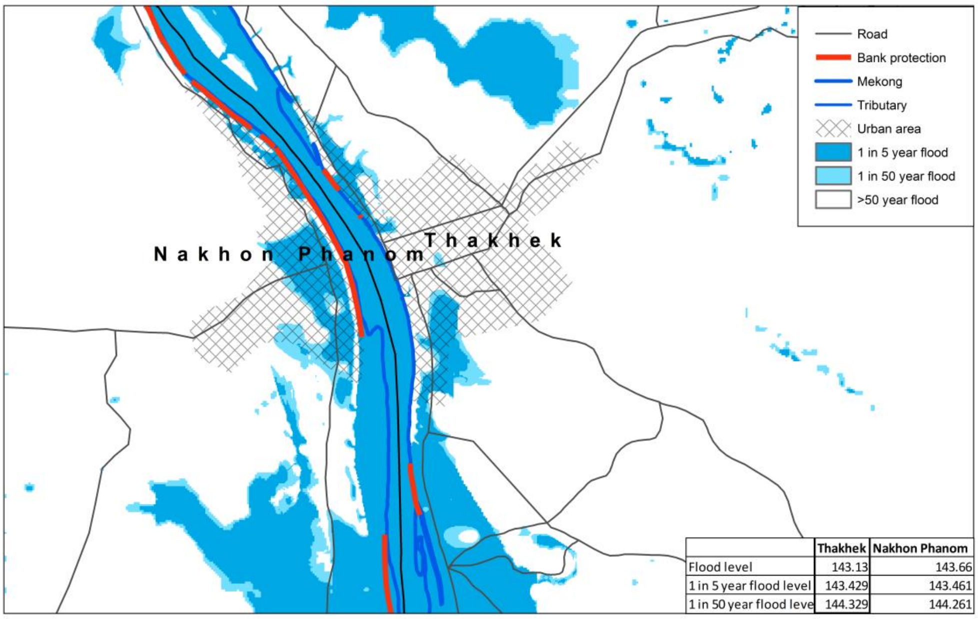
Assumption: Water Levels of certain frequency based on historic record can flood lower lying land. In reality flood defences will reduce the actual extent such as at Vientiane where there is a major defence embankment.



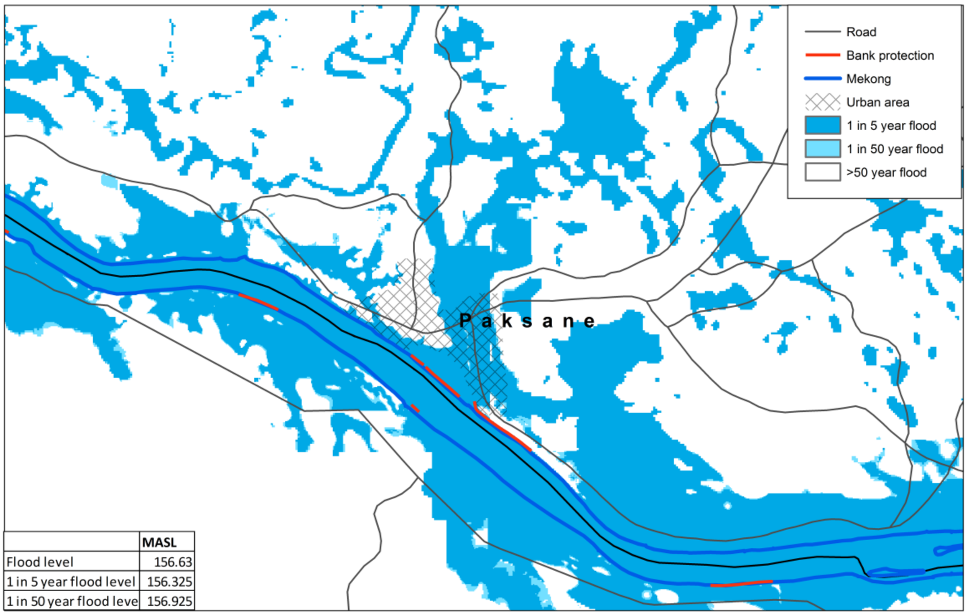



Road
Bank protection
Mekong
Tributary
Urban area
1 in 5 year flood
1 in 50 year flood
>50 year flood
Vientiane
Nong Khai
MASL
Flood level 170.54
1 in 5 year flood level 169.84
1 in 50 year flood leve 171.24

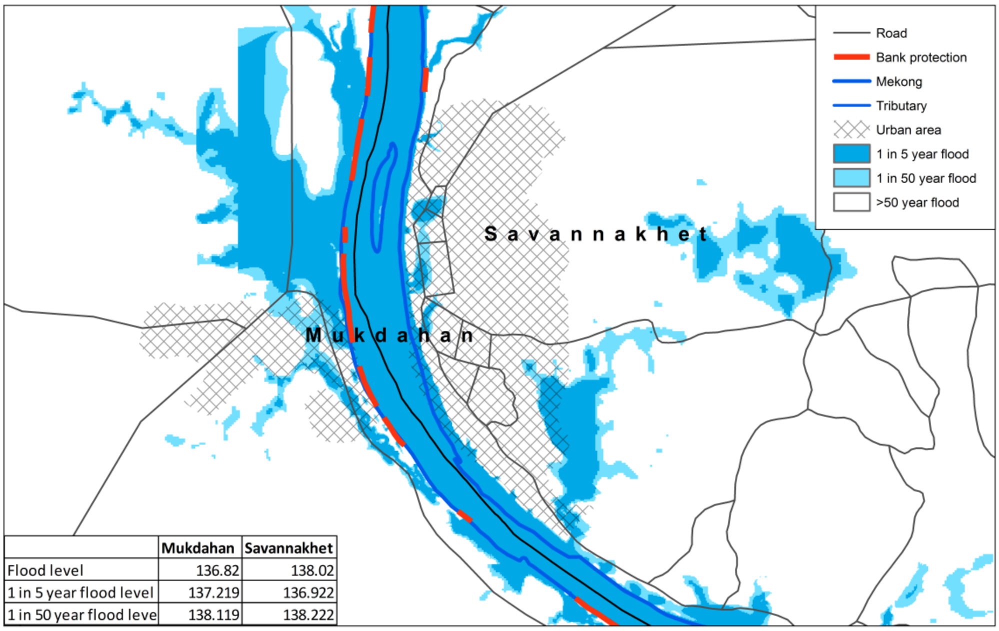

MASL
Flood level 165.85
1 in 5 year flood level 166.048
1 in 50 year flood level 167.548
Road
Bank protection
Mekong
Tributary
Urban area
1 in 5 year flood
1 in 50 year flood
>50 year flood
Nong Khai



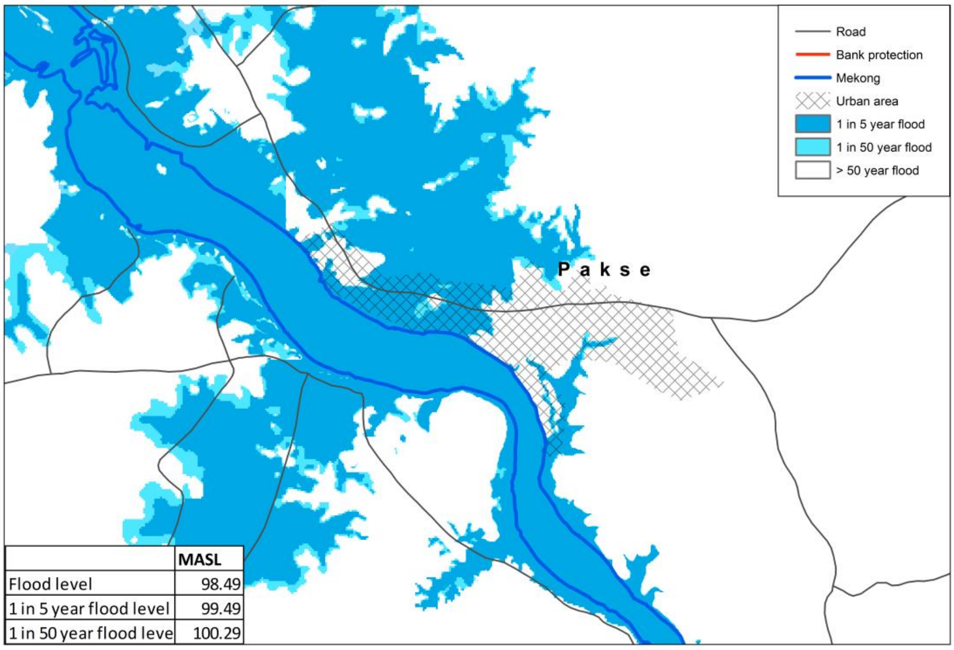
	Thakhek	Nakhon Phanom
Flood level	143.13	143.66
1 in 5 year flood level	143.429	143.461
1 in 50 year flood leve	144.329	144.261



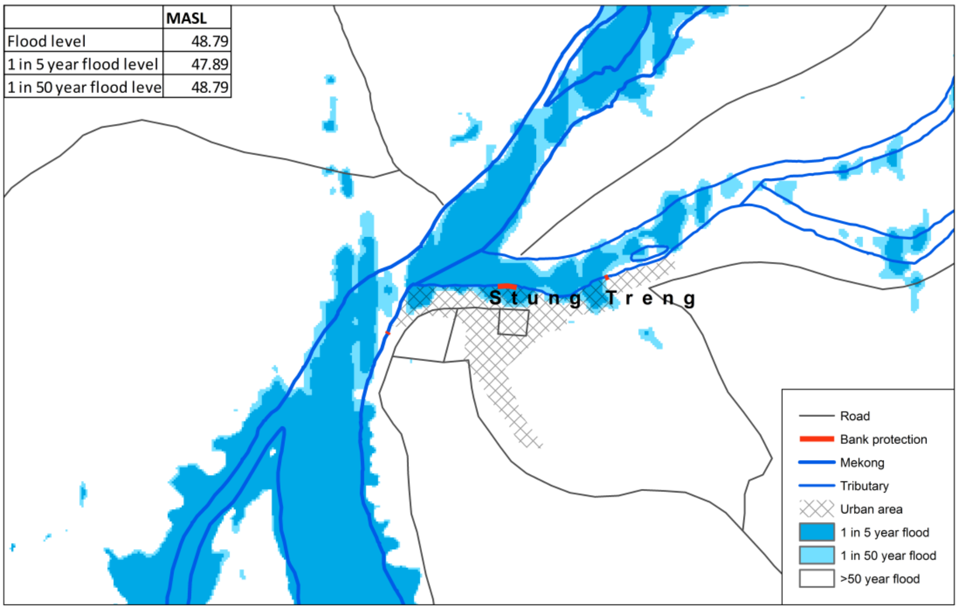
	MASL
Flood level	156.63
1 in 5 year flood level	156.325
1 in 50 year flood leve	156.925

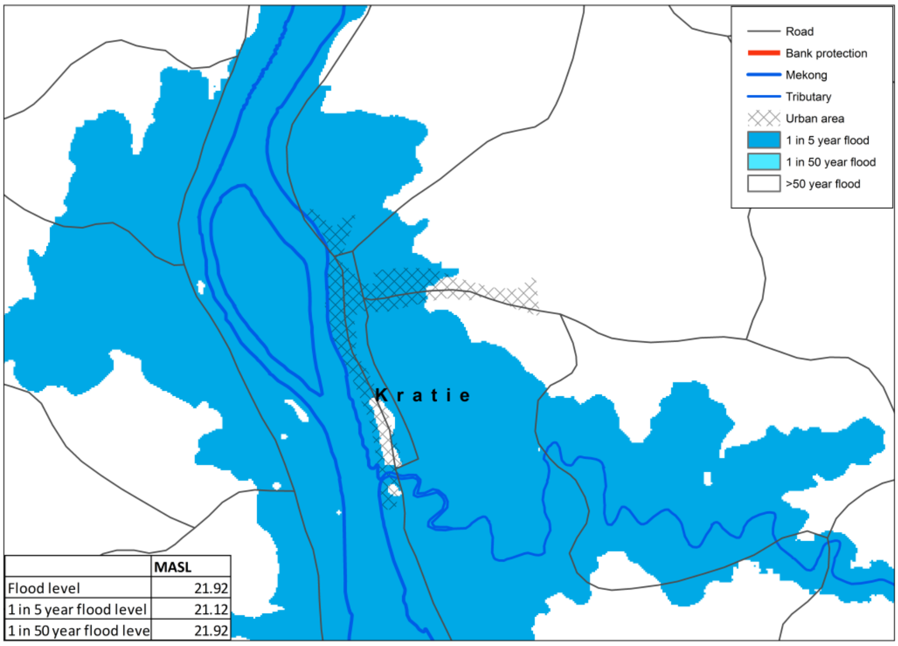


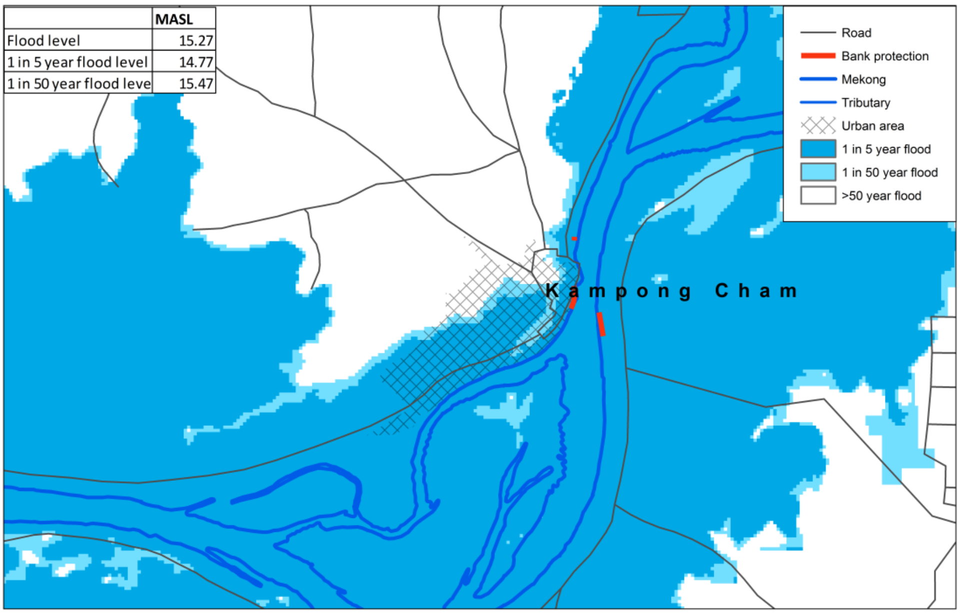
	Mukdahan	Savannakhet
Flood level	136.82	138.02
1 in 5 year flood level	137.219	136.922
1 in 50 year flood leve	138.119	138.222

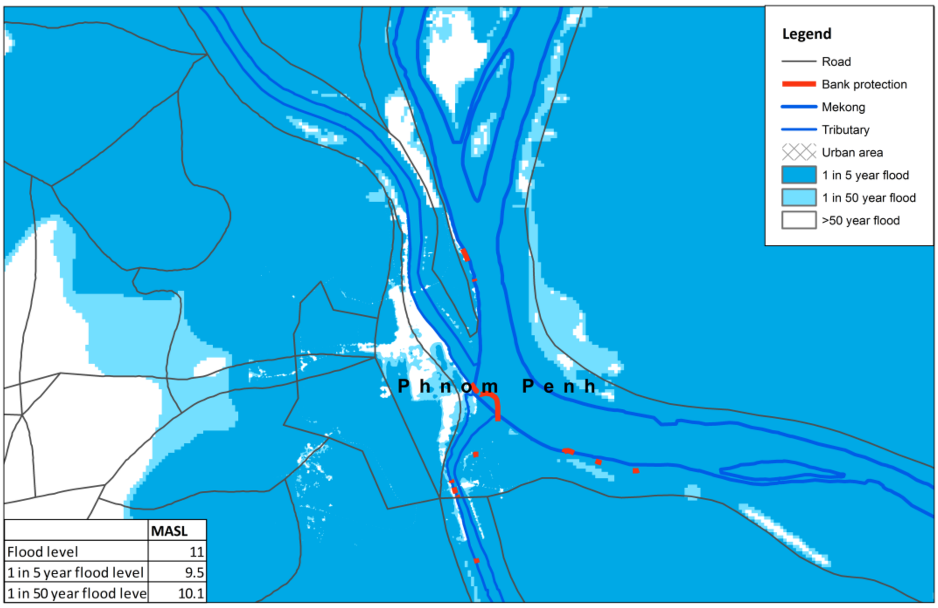


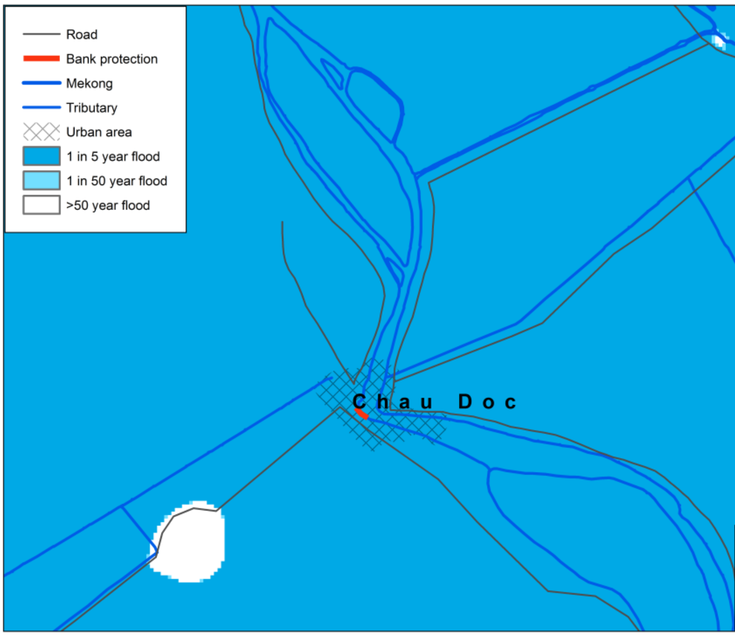
	MASL
Flood level	98.49
1 in 5 year flood level	99.49
1 in 50 year flood leve	100.29


MASL
Flood level 48.79
1 in 5 year flood level 47.89
1 in 50 year flood leve 48.79
Stung Treng
Road
Bank protection
Mekong
Tributary
Urban area
1 in 5 year flood
1 in 50 year flood
>50 year flood


Road
Bank protection
Mekong
Tributary
Urban area
1 in 5 year flood
1 in 50 year flood
>50 year flood
Kratie
MASL
Flood level 21.92
1 in 5 year flood level 21.12
1 in 50 year flood leve 21.92


MASL
Flood level 15.27
1 in 5 year flood level 14.77
1 in 50 year flood leve 15.47
Road
Bank protection
Mekong
Tributary
Urban area
1 in 5 year flood
1 in 50 year flood
>50 year flood
Kampong Cham


Legend
Road
Bank protection
Mekong
Tributary
Urban area
1 in 5 year flood
1 in 50 year flood
>50 year flood
Phnom Penh
MASL
Flood level 11
1 in 5 year flood level 9.5
1 in 50 year flood leve 10.1



	MASL
Flood level	15.27
1 in 5 year flood level	14.77
1 in 50 year flood level	15.47

Appendix F Floodplain Development in F3

The draft development plans for 2060 formulated as part of Task 3 of the FMMP Initial Studies project have been used to formulate a 2040 scenario for 2040. After completing the simulation runs to assess the impact of this scenario on flood behaviour, FMMP will be able to identify plausible flood protection infrastructure for the 2040 scenario. At present FMMP envisages running a number of sub-scenarios for other thematic areas to assess the specific impact in terms of flood damages.

The proposed 2040 scenario will include:

- *Expansion of Urban Centres*
  - Upstream Centres above Pakse such as Chiang Saen, Luang Prabang, Vientiane, Nong Khai, Nakhon Phanom, Thakhek, Mukdahan Khong Chiam
  - Middle reaches Pakse, Stung Treng, Kratie
  - Tonle Sap Kampong Chhnang, Kampong Thom, Siem Reap, Battambang, Sisophon
  - Cambodia Floodplain Phnom Penh, Ta Khmao, Takeo, Kampong Cham, Prey Veng
  - Vietnam Delta Chau Doc, Tan Chau, Long Xuyen, Cau Lanh, Can Tho, My Tho, Rach Gia, Soc Tran, Vinh Long etc., compatible with Mekong Delta Plan (2013).

- *Upgrading National Road Networks*
  - NR 1, NR 2, NR 3, NR 4, NR 5, NR 6, NR 7 in Cambodia

- *Ring Roads around Phnom Penh*
  - Second Ring Road (2040)
  - Third Ring Road (2060)

- *Expansion Industrial Areas in Cambodia*
  - Expansion along NR 3 and NR 4 towards southwest
  - Areas in Vietnam as proposed in Mekong Delta Plan.

- *Conveyance Corridors*
  - Corridor linking Mekong - Tonle Sap
  - Corridor towards Svay Rieng
  - Relief corridor to Gulf of Thailand

- *Irrigation Schemes*
  - Around 500,000 hectares of floodplain to be defined by Sectoral studies and locations to be decided

- *Move towards intensive agriculture with flood protection*

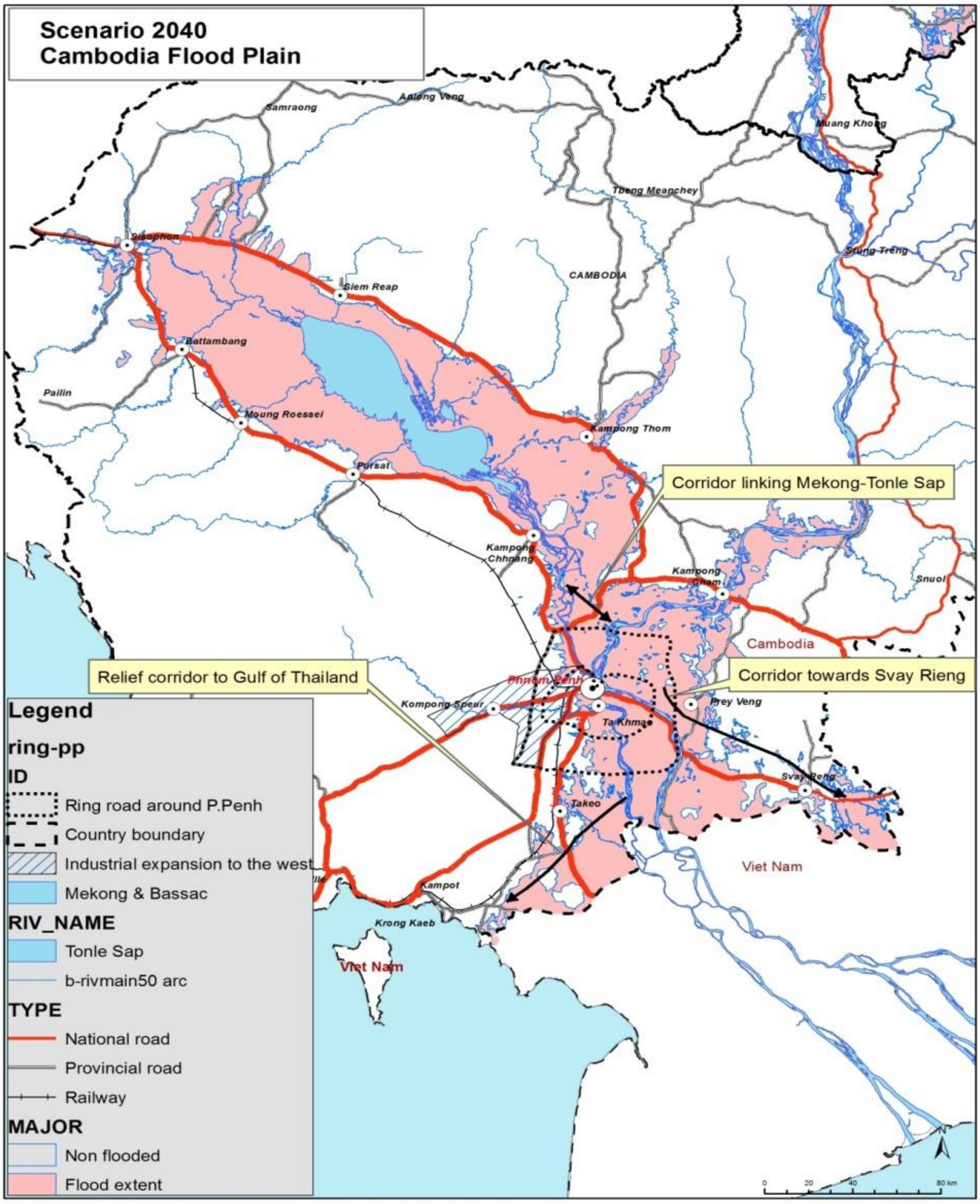


Figure 1: Scenario 2040 for Cambodian Floodplains

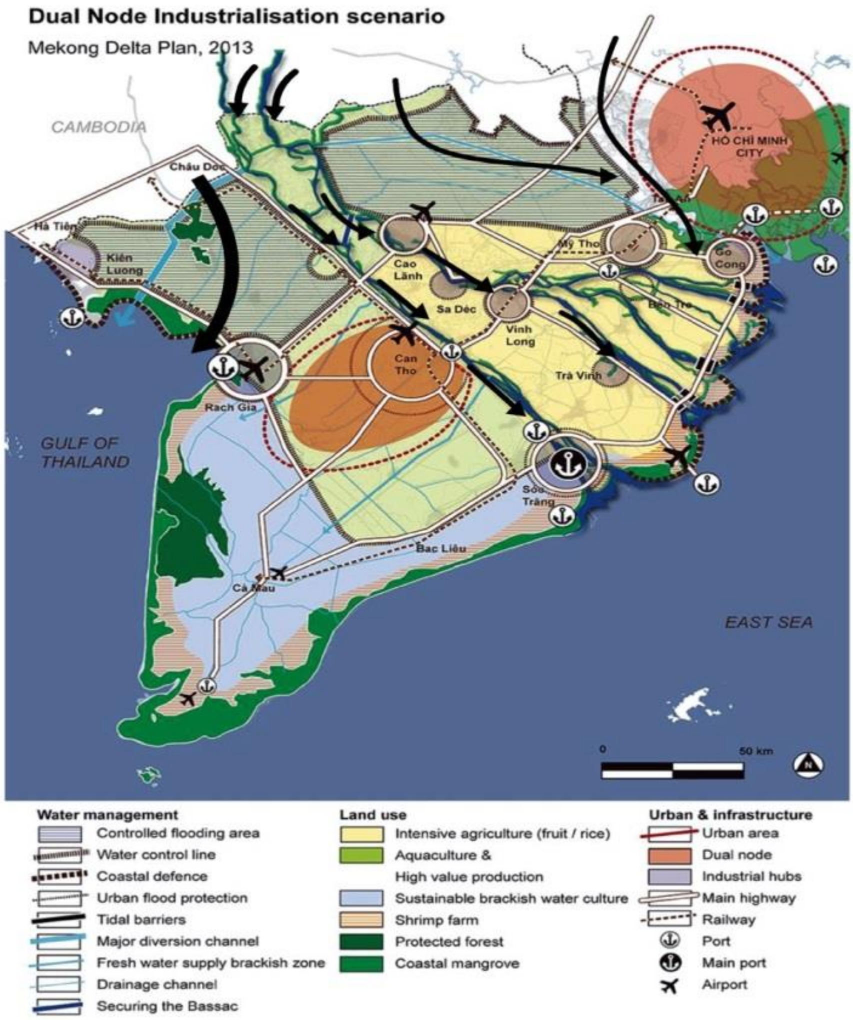


Figure 2: Scenario 2040 to be deducted from Mekong Delta Plan, 2013