GREATER MEKONG SUB-REGION FLOOD AND DROUGHT RISK MANAGEMENT AND MITIGATION PROJECT

Consulting Services for Support to the National Flood Forecasting Centre and to Improve Hydraulic Design Standards

Contract Number: GMS-FDRMMP-CS-003

FLOOD PROTECTION AND DROUGHT MITIGATION MEASURES

FINAL DRAFT REPORT

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Executive Summary

The Royal Government of Cambodia has received financial support from the Asian Development Bank to implement the Greater Mekong Sub-Region Flood and Drought Risk Management and Mitigation Project (GMS-FDRMMP), which is comprised of three components. Component 1.0 is to improve the National Flood Forecasting Centre (NFFC) and to propose climate resilient design guidelines for structural flood and drought mitigation. This report focuses on the second objective and is a primer to the development of climate resilient design guidelines for structural flood and drought control measures in Cambodia.

The report presents an overview of flood and drought protection measures and details a comprehensive approach to flood and drought mitigation for Cambodia. The report presents the current thoughts on climate change and climate variability projections for Cambodia. These projections are further discussed in light of the climate and hydrologic factors that influence floods and droughts. The concepts of vulnerability and adaption are presented and highlighted. The report reviews existing RGoC national flood and drought response and mitigation strategies. As well, a range of flood and drought mitigation measures are presented. A preliminary discussion on the cost and potential benefits of the proposed flood and drought measures is presented. Finally, the report makes recommendations on refinements to the government's flood and drought risk mitigation strategy. This report satisfies the deliverable for WBS 600. The original plan was for a Cost Analysis Report on Residual Risk Associated with Various Protection Measures for the selected study area to be developed. However, due to the limited flood damage data that is available at a disaggregated level for various flood hazard levels, it was meaningless to conduct a cost analysis considering residual risks associated with various levels of protection.

Climate change projections for Cambodia indicate a wetter rainy season with a greater percentage of the total rain for the rainy season resulting from extreme events, and a dryer dry season with perhaps less rain but higher temperatures. Projected runoff is to be higher and sea level rise will have implications for existing flood prone areas. Cambodia is expected to experience a reduced number of intense cyclones. These climate change projections have implications for floods and droughts in Cambodia.

In addition to climate change, upstream developments such as dams and future development on the basin's floodplains will affect flood behaviour and flood risk in the Lower Mekong basin. Potential floodplain changes include the development of new infrastructure, increased population, changes to land-use, and a higher standard of living. The critical flood attenuation function of the Cambodian floodplain and the Tonle Sap Lake system is potentially threatened by floodplain development and loss of flood conveyance due to infrastructure. The Cambodian floodplain is currently much less developed than the Mekong delta and this potential for new floodplain development may have a significant effect on future flood risk and vulnerability. The raising of levees and roads, the installation of culverts and bridges to restrict natural flood flow pathways, and the greater compartmentalization of flood water retention areas all have the potential to affect flood risk and increase vulnerability.

Therefore, it is important to recognise the role that development and land use changes have on floods and droughts. This recognition draws attention to the need for a more encompassing perspective in which structural measures and land use changes in response to social-economic initiatives must be considered. This perspective must not only consider how floods and droughts will affect these developments and initiatives and the need for protection, but more importantly consider how these developments and initiatives will increase or decrease flood and drought vulnerability. This broader perspective considers both the structural and non-structural measures to reduce vulnerability to floods and droughts.

The report discusses structural and non-structural approaches to address flood and droughts hazards. Structural measures aim to reduce flood risk by controlling the flow of water. Structural measures range from engineered structures, such as flood defences and drainage channels to more natural and sustainable complementary or alternative measures such as wetlands and natural buffers. Non-structural measures are actions taken to mitigate flood and drought loss and damages through better planning and management of watershed development. Non-structural measures address flood and drought risks by building the capacity of people to cope with floods and droughts. As such, building capacity and awareness are key components of a non-structural flood and drought mitigation and risk reduction strategy. Non-structural measures include activities such as having in place an early warning system, building and zoning codes, supportive policies and strategies, education and awareness initiatives, and institutional capacity.

The report notes that the consequences of climate change and future developments in the floodplain for a 2060 design horizon are significant. The 2060 design horizon provides a design life of some 40 years for infrastructure currently in the planning stage. Sea level rise is expected to approach 0.5 m by 2060, which will increase water levels at Phnom Penh by some 0.2 m. Peak water levels at Phnom Penh for a 1:100 year event is expected to approach 0.3 m for a moderate climate change scenario and over 1.2 m for the extreme scenario. This increase in water level for even the moderate scenario is expected to lessen the existing flood protection works to less than a 1:20 year event. The duration of flooding is predicted to be extended by 14 days for a moderate scenario.

Approaches to lessen the negative affect of floods and droughts may consist of structural and non-structural measures. A number of studies for the region have raised caution with respect to the wide spread use of structural measures given the implications for loss of the natural floodplain function. The MRC Flood Management and Mitigation Programme 2011-2015 conducted a number of studies related to flood challenges and flood management strategies. The findings of these studies hold true today and provide the bases for recommendations on refinements to the Cambodia's flood and drought risk mitigation strategy. Adaptation is the core mitigation strategy that emerges combined with selected and cautious use of structural measures.

The report concludes that planning in an adaptive way is a strategic direction for flood and drought risk management in Cambodia. Previous studies have referred to this strategic direction as "living with floods". The approach considers the use of structural protection works by flood proofing of settlements and transportation infrastructure and adaptations such as the use and/or development of less vulnerable rice varieties to inundation. Drought adaptation approaches suggest greater use of low intensity irrigation, use of drought tolerant crop varieties, and, greater use of water retention schemes and groundwater. Whether the adaptation approach is for floods or droughts, considerations must be given to maintaining sensitive and valuable ecosystems such as seasonally-inundated riparian forests; seasonal wetlands including marshes, small pools and pools; and seasonally inundated grasslands. These ecosystems are important as a habitat for a variety of fish and water birds and for the sustenance of the inland fisheries.

In summary, changes on the floodplain as well as climate change will have significant implications leading to higher flood water levels, longer duration of flooding, and increased flows. It is apparent that the floodplain system with the current infrastructure cannot absorb the increases in extreme floods that most of the climate scenarios indicate. The relative fragility of the flood control system for cities such as Phnom Penh and secondary towns such as Kampong Cham are highlighted by the results of the FMMP study. While the people of Cambodia have adapted to the occurrence of annual floods and are accustom to "living with floods", they are less prepared for droughts that occur with a frequency of once in every three years. The findings of this primer must be considered when developing climate resilience design guidelines for structural flood and drought control measures in Cambodia.

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List of Acronyms and Abbreviations

ADB	Asian Development Bank
AusAID	Australian Agency for International Development
AWS	Automatic Weather Station
BDP	Basin Development Plan
CBDRM	Community Based Disaster Risk Management
CBOs	Community-Based Organization
CNMC	Cambodian National Mekong Committee
CSO	Civil Society Organization
DEM	Digital Elevation Model
DIS	Database and Information System
DHRW	Department of Hydrology and River Works
DOM	Department of Meteorology
DSF	Decision Support Framework of MRC
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
EWS	Early Warning System
FMMP	Flood Management and Mitigation Programme
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	Greenhouse Gases
GMS	Greater Mekong Sub-Region
GMS-FDRMMP	Greater Mekong Sub-Region Flood and Drought Risk Management and Mitigation Project
GTZ	German Technical Cooperation
ICT	Information and Communications Technology
IDPs	International Development Partners
IPCC	Intergovernmental Panel on Climate Change
IRBM	Integrated River Basin Management
IWRM	Integrated Water Resources Management
M-IWRMP	Mekong Integrated Water Resources Management Project
MOWRAM	Ministry of Water Resources and Meteorology
M&E	Monitoring and Evaluation
MRC	Mekong River Commission
MRC-RFMMC	MRC Regional Flood Management and Mitigation Centre

NCDM	National Committee for Disaster Management
NFFC	National Flood Forecasting Centre
NGO	Non-Governmental organization
O&M	Operation and Maintenance
PEMSEA	The Partnership in Environmental Management for the Seas of East Asia
PIO	Project Implementation Office
RB	River Basin
RBO	River Basin Organization
RBU	River Basin Unit
RCPs	Representative Concentration Pathways
RGoC	Royal Government of Cambodia
SOP	Standard Operating Procedures
SSEPs	Shared Socio-economic Pathways
SRES	Special Report on Emissions Scenarios
TA	Technical Assistance
TSA	Tonle Sap Authority
WB	World Bank
WBS	Work Breakdown Structure
WMO	World Meteorological Organization
WUAs	Water User Associations

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1. Introduction

1. The Royal Government of Cambodia (RGoC) has received financial support from the Asian Development Bank to implement the Greater Mekong Sub-Region Flood and Drought Risk Management and Mitigation Project (GMS-FDRMMP). Component 1.0 of project is to improve the National Flood Forecasting Centre (NFFC) and to propose climate resilient design guidelines for structural flood and drought mitigation. One objective is to strengthen the National Flood Forecasting Centre (NFFC) to better forecast floods and droughts and to enhance NFFC's contribution to regional data, information, and knowledge for the improved management of risks associated with floods and droughts. A second objective is to propose climate resilient design guidelines for structural flood and drought control measures in Cambodia. The results will enable the RGoC to reduce the consequences of floods and droughts as well as to undertake measures to better design structural and non-structural measures with the objective of reducing the negative effects that these natural disasters cause.

2. This report focuses on the second objective and is a primer to the development of climate resilient design guidelines for structural flood and drought control measures in Cambodia. When undertaking the development of guidelines, it is prudent to first understand the mechanics of the flood and drought systems in the region as well as projected climate change implications. The Lower Mekong basin has a complex floodplain where floods exhibit many positive benefits as well as have negative consequences. The complexity and role of the floodplain must be understood as it has significant influence on the extend, duration, and storage of flood water. A comprehensive study conducted by the Mekong River Commission (MRC) under the Flood Management and Mitigation Programme (FMMP) from 2011 to 2015 through the FMMP Initial Studies Project provides valuable insight in how the flood zones behaved. Accordingly, the findings of the FMMP study are used extensively in the preparation of this report.

3. Conversations about climate resilience is incomplete without incorporating the concepts of vulnerability and adaptation. The definition of resiliency is the ability to recover from a negative event, such as natural hazards and a changing climate. Adaptation involves preparations beforehand and strategies for recovery and adjustment. The adaptive capacity refers to a community's capacity to create resilience infrastructure, to develop response systems, and to take action. Whereas, vulnerability is an assessment of adaptive capacity, sensitivity, and exposure. Sensitivity and exposure are both tied to socioeconomic and geographic elements that vary widely in differing communities and geographic regions. The report considers the aspect of vulnerability and adaption in the development of climate resilient design guidelines.

4. This report presents an overview of flood and drought protection measures and details a comprehensive approach to flood and drought mitigation for Cambodia. The report presents the current thoughts on climate change and climate variability projections for Cambodia. These projections are further discussed in light of the climate and hydrologic factors that influence floods and droughts. The concepts of vulnerability and adaption are presented and highlighted. The report reviews existing RGoC national flood and drought response and mitigation strategies. As well, a range of flood and drought mitigation measures are presented. A preliminary discussion on the cost and potential benefits of the proposed flood and

drought measures is presented. Finally, the report makes recommendations on refinements to the government's flood and drought risk mitigation strategy.

5. This report satisfies the deliverable for WBS 600. The original plan was for a Cost Analysis Report on Residual Risk Associated with Various Protection Measures for the selected study area to be developed. However, due to the limited flood damage data that is available at a disaggregated level for various flood hazard levels, it was meaningless to conduct a cost analysis considering residual risks associated with various levels of protection.

2. Flood and Drought Considerations

2.1. Background

6. Cambodia (Figure 1) is situated in the southwestern part of Indochinese peninsula, bordered by Thailand and Lao PDR to the North, Vietnam to the East and South, and the Gulf of Thailand to the West. The area of Cambodia is 181,035 km^2. About 75% of the country is located at elevations of less than 100 metres above mean sea level, and its topography can be grouped into three types: (i) the low swampy region around Tonle Sap Great Lake and the rivers valleys of Mekong and Bassac River; (ii) the mountainous and highland area including a plateau region in the northeast and east of the Mekong River; and (iii) the coastal zone in the west covering the Kompot, Koh Kong, and Preah Sihanuk Provinces.

Figure 2: Location Map - Cambodia

7. Cambodia's population of 16 million is predominantly rural based and most of the population is subsistence farmers or fishers. The economy of Cambodia follows an open market system (market economy) and has seen rapid economic progress in the last decade. Cambodia had a GDP of $18.05 billion in 2015. However, per capita income, although rapidly increasing, is low compared with most of its neighbouring countries. Cambodia's two largest industries are textiles and tourism, while agricultural activities remain the main source of income for many Cambodians living in rural areas. The service sector is heavily concentrated on trading activities and catering-related services.

8. The monsoon season for the Mekong River basin typical begins in June and persists to late October. Rainfall during this period accounts for 80 to 90% of the total annual flow of the Mekong river (MRC 2010).

The annual flood pulses sustain the productivity of low-lying agricultural land as well as of the world-renowned Mekong freshwater fisheries. During the monsoon season the Tonle Sap Great Lake system functions as a natural storage reservoir for Mekong floodwaters and can increase from a dry season area of 2,500 km^2 to a typical flood season area of 15,000 km^2. During a typical flood season, the average depth of the lake increases from 1 m to 6 m and can increase up to 9 metres. The annual flood pulse plays a vital role in agriculture and in supporting environmental integrity. Its average annual benefit to Cambodia of is estimate to be $8 to $10 billion USD. While annual floods have significant benefits, severe flooding can cause significant damage to communities, infrastructure, and agriculture crops, disrupt economic activities, endanger human health, and result in loss of life. Examples are Typhoon Ketsana in 2009, and Typhoons Haima and NokTengin in 2011. The average annual cost of the resulting floods in the Lower Mekong Basin was estimated to be $60 to $70 million USD. When considering the benefits and cost of floods, the challenge of flood management and mitigation is to reduce the costs and negative impact of flooding while preserving flood benefits.

9. Unlike floods, droughts have less apparent benefits. Drought can result in food and water shortages, loss of income, and higher levels of disease. In Cambodia, the occurrence of relatively moderate drought events has significant impact given the high level of vulnerability and limitations in the ability of rural people to cope with the impact of drought events. Under a normal year, typical rainfall distribution is from May to October with heavy rainfall from August to mid-October. A dry spell of about 2 to 3 weeks in July and August is typical. In a year when the inter-monsoon dry period is extended too long, an agricultural drought can occur in addition to the late rain and early end of monsoon season. Droughts are damaging to agriculture, especially rice, and can result in a total loss of crops, livestock, and fisheries. Given the relatively high frequency of moderate to severe drought in the Lower Mekong basin, the cost of droughts is significantly higher than the cost of flooding. As the climate warms, the cost of droughts is expected to increase and will continue to be greater than those of flooding.

10. Floods, droughts, and extreme weather are the dominant hazards in Cambodia and cause loss of life, damage agricultural production, and threaten livelihoods. The occurrence of significant flood events and periods of droughts has increased in recent years. The increase of these severe events tends to support climatic change predictions, which suggest there will be increased variability in the climate with an increase in the occurrence of more extreme weather events as the earth warms. The effect of any increase in extreme flood and drought events will directly affect vulnerable populations, exacerbate food insecurity, and result in an increase in related damages. These factors all have a direct constraining influence on poverty alleviation efforts.

11. An important consideration with respect to floods and droughts in Cambodia is the transboundary nature of the Mekong River basin. Much of the floodwaters in Cambodia are derived from upstream countries, including Vietnam, and in some provinces floods and droughts occur within the same season. Therefore, effective flood and drought management hinges on regional cooperation, information sharing, and the development of region-specific solutions.

12. Natural hazards have drastic effects on its population and pose a serious challenge for water resources management and poverty alleviation in the country. Flood and drought risk is one of the most significant factors to consider when addressing poverty reduction and economic development in Cambodia Consequently, the Royal Government of Cambodia has increased its effort to improve natural disaster preparedness. As well, efforts are being made by the Mekong River Commission and its Member Countries to devise strategies that aim to decrease the vulnerability of people in the Mekong basin, especially in agricultural communities. Flood and drought proofing coupled with climate adaptation strategies to reduce risks from floods and droughts are key priorities for sustainable development, ensuring the health and safety of the population, and maintaining environmental integrity.

2.2. Future Climate Change Projections and Implications

13. The Intergovernmental Panel on Climate Change (IPCC) notes that in the coming decades, global average temperatures will increase, rainfall patterns will change, extreme weather events will become more severe, sea levels will rise, and numerous other environmental changes will occur (IPCC 2007). However, the degree of change varies because the climate change implications are based on a number of emission and development scenarios. The emission scenarios consider low, moderate, and high emission projections for arrange of assumptions related to population growth, technological development, economic growth, and energy sources. This variability among scenarios accounts for the wide margin in predictions. A second layer of variability is due to the uncertainty associated with ecological feedback in the system. Uncertainty increases with the complexity of the system and as predictions move further in time along ecological and social processes. It is important to note that the scenarios used in earlier climate change assessment reports were replaced with Representative Concentration Pathways (RCPs) for IPCC's Fifth Assessment Report (AR5) in 2014. The RCPs supersedes the Special Report on Emissions Scenarios (SRES) projections published in 2000. The RCPs consider four greenhouse gas concentration, not emissions, trajectories adopted by the IPCC. The RCPs are consistent with a wide range of possible changes in future anthropogenic (human) greenhouse gas (GHG) emissions. RCP2.6 assumes that global annual GHG emissions measured in CO_2-equivalents peak between 2010-2020, with emissions declining substantially thereafter. Emissions in RCP4.5 peak around 2040, then decline. In RCP6.0 emissions peak around 2080, then decline. In RCP8.5 emissions continue to rise throughout the 21st century. The four RCPs have consistent socio-economic assumptions but these may be substituted with the Shared Socio-economic Pathways (SSEPs), which are anticipated to provide flexible descriptions of possible futures within each RCP. The RCPs and SSEPs are used for climate modelling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted and the actions taken to limit these emissions.

14. The average temperature in Cambodia has increased since 1960 by 0.8°C, and with it the frequency of unusually hot days and nights has increased (McSweeney et al. 2008). The climate models project a further 0.3 to 0.6°C increase by 2025 (MOE 2002). Modelled estimates put the expected warming at 0.7 to 2.7°C by the 2060's (McSweeney et al. 2008). The temperature increases are expected to be more severe from December to June.

15. All climate change models agree that rainfall in Cambodia will increase, but the magnitude of change is uncertain. Estimates of the increase vary from as little as 3% to as much as 35% (ICEM 2009). Models predict that the increase in rainfall will occur during the wet season, bringing more flooding, and that precipitation in the dry season will be unchanged or lower (Eastham et al. 2008). Rainfall is expected to increase more in the lowlands than in the highlands, with precipitation and flooding increasing predominantly in the central agricultural plains, which are already vulnerable to flooding and drought.

16. Climate change will bring more extreme weather events such as storms, heat waves, droughts and floods. Damage from intense cyclones has increased significantly in Cambodia in recent decades (Cruz et al. 2007) and may worsen. The following figure (WorldFish Centre 2009) summarizes the expected change for a number of factors, where the thickness of the arrows indicates the degree of certainty in the findings. Not captured in the figure is the expected change to sea level rise, which has implications for the lower portion on the Mekong River basin in Cambodia. The projected sea level rise along the Southeast Asian coastline relative to 1986 to 2005 is expected to exceed 50 cm above current levels by 2060 and approach 100 cm by 2090 (World Bank 2013). As well. the intensity and maximum wind speed of tropical cyclones making landfall is projected to increase significantly for Southeast Asia. However, the total number of cyclones reaching landfall may be significantly reduced. Damages may still rise as the greatest impacts are caused by the most intense storms. Extreme rainfall associated with tropical cyclones is expected to increase by up to a third. It is important to note that the World Bank 2013 report developed its projections on a 4°C increase under a RCP8.5 scenario.

Factor	Change predicted	Trend [a]	Remark
Temperature	+0.3° to +0.6° by 2025	→	
Rainfall in wet season	+3% to +35%	→	Direction of change certain, but magnitude uncertain
Rainfall in dry season	No change or decrease	↘	
Extreme events	More frequent and more intense	→	Extreme events = floods, drought, storms
Runoff	+21%	→	Higher sediment load in water, impact on fishery productivity
Tonle Sap level in rainy season	+2.3 meters	→	Increased rainfall in wet season will raise flood levels
Tonle Sap level in dry season	+0.1 meter	→	

Figure 2: Expected Implications of Climate Change

17. In summary, the climate change projections for Cambodia indicate a wetter rainy season with a greater percentage of the total rain for the rainy season resulting from extreme events, and a dryer dry season with perhaps less rain but higher temperatures. Projected runoff is to be higher and sea level rise will have implications for existing flood prone areas. Cambodia is expected to experience a reduced number of intense cyclones.

2.3. Implications of Development and Landscape Changes

18. In addition to climate change, upstream developments such as dams and future development on the basin's floodplains will affect flood behaviour and flood risk in the Lower Mekong basin. Potential floodplain changes include the development of new infrastructure, increased population, changes to land-use, and a higher standard of living.

19. The Cambodian floodplain and the Tonle Sap Lake system provides a critical flood attenuation function that is potentially threatened by floodplain development and loss of flood conveyance due to infrastructure. The Cambodian floodplain is currently much less developed than the Mekong delta and this potential for new floodplain development may have a significant effect on flood risk and vulnerability. The raising of levees and roads, the installation of culverts and bridges to restrict natural flood flow pathways, and the greater compartmentalization of flood water retention areas all have the potential to affect flood risk and increase vulnerability.

20. The possible footprint of Phnom Penh and other major towns along the Mekong River and around Tonle Sap Lake will continue to expand as the population increases and there is greater rural to urban migration due to better social-economic opportunities in the urban areas. The growing urban footprint has implications for increasing vulnerability due to the expansion of the densely-populated areas, which may be affected by flood water, as well as may significantly increase the damages that result from flooding due the higher density and higher valued properties and business located in urban areas. As well, the urbanization of the floodplain will restrict the natural flood attenuation and normal flood pathways resulting in higher flood levels and perhaps longer periods of flood inundation outside of the urban areas. The mitigation measures for urban centre is often flood protection through the use of protections levels and dikes. While these structural measures are sufficient for less extreme flood events, they significant increase the urban centre's vulnerability to extreme events that exceed the design capacity of these protection measures resulting in catastrophic losses.

21. The implications of development and landscape changes on vulnerability due to drought and vice-versa is much less direct. Droughts are defined by the limited available of water to satisfy the social-economic and ecological needs of the region. Development may increase the demand for water and hence artificially increase the frequency of water shortages and the regions vulnerability to drought. However, drought is considered more of a naturally driven event that is directly influenced by the natural climate conditions of the region and changes in rainfall and temperature patterns over the short to long term.

22. Therefore, it is important to recognise the role that development and land use changes have on floods and droughts. This recognition draws attention to a more encompassing perspective in which structural

measures and land use changes in response to social-economic initiatives must be to consider not only from how floods and droughts will affect these developments and initiatives and the need for protection but, more importantly, how these developments and initiatives will increase of decease flood and drought vulnerability. This broader perspective considers both the structural and non-structural measures to reduce vulnerability to floods and droughts.

2.4. Vulnerability, Adaptation, Mitigation, and Risk

23. The concepts of vulnerability, risk, and adaptation to natural hazards are important to understand when developing strategies and measures for flood and drought mitigation. Natural hazards, such as floods, droughts, extreme weather, and rising sea levels cause economic, social, and ecological loss by damaging property, by restricting access to food, by increasing the potential for disease, and by limiting the population's ability to earn a livelihood. Vulnerability is defined as a function of exposure, sensitivity, and adaptive capacity. In the context of vulnerability, exposure is the nature and degree to which a system is exposed to the natural hazard, and sensitivity is the degree to which a system is affected, either adversely or beneficially. Exposure and sensitivity are both tied to socioeconomic and geographic elements that vary widely in differing communities and geographic regions. Adaptive is defined as the ability of a system to moderate the potential damage from it, to take advantage of its opportunities, or to cope with its consequences.

24. Adaptation involves making adjustments in our decisions, activities, and ways of thinking in response to observed or expected changes, with the goal of reducing harm and taking advantage of potential opportunities. Adaptation involves preparations beforehand and strategies for recovery and adjustment. Adaptation can include behavioural changes, operational modifications, technological interventions, planning changes and revised investment practices, regulations and legislation. Adaptive capacity refers to a community's or sector's capacity to create resiliency infrastructure, to develop response systems, and to take action. While adaptation in the natural environment occurs spontaneously, adaptation in human systems often benefits from careful planning that is guided by both scientific research and detailed understanding of the systems involved. Adapting to natural climate variability and a more variable and changing climate entails taking measures first to reduce the negative effects of the climates variability and extremes and second to take advantage of the positive effects. Policies, regulations and guidelines are mechanisms that can be used to raise awareness and encourage or require adaptive action. Planned adaptation takes time as it requires research, stakeholder engagement and adjustments to policies and regulations. Many sectors are starting to use adaptive management approaches to deal with changes in climate and other stressors and related uncertainties. Adaptive management involves ongoing monitoring, adjusting, experimenting and re-evaluating, and requires a flexible and responsive approach to adaptation.

25. Mitigation means actions to reduce the severity or seriousness of an outcome. Mitigation can involve human interventions to reduce the source of and to enhance sinks for the natural hazard. Mitigation is different than adaptation as it focuses on activities which reduce or eliminate the conditions that are linked to the occurrences of the natural hazard. Whereas adaptation as noted above encompasses adjustments in practices, processes, or structures in response to variability and change in the climate and occurrences

of extreme events. A difference between mitigation and adaptation is subtle and may be best thought of as actions to reduce the hazard tend to be mitigation oriented and actions to live with the hazard tend to be adaptation oriented. However, in today's research and policy literature the term adaptation tends to encompass both concepts and is the term more broadly used.

26. The consideration of risk has also emerged as a key concept in policies and actions related to disaster management. Risk is generally described as the probability of occurrence of an adverse event multiplied by the consequences of that event should it occur. Therefore, the risk that an event may have is a function of the events likelihood of occurrence and the consequence of the event. Extreme flood and drought events are increasing in frequency, intensity, and duration, increasing the risk of vulnerable populations. The severity of these events can be best shown in a risk space as present in the Figure 3.

	Consequence Level				
Likelihood Level	**Insignificant**	**Minor**	**Moderate**	**Major**	**Catastrophic**
Almost Certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Low	Medium	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Medium	Medium
Very rare	Low	Low	Low	Low	Medium
Almost incredible	Low	Low	Low	Low	Low

Figure 3: Example Risk Matrix considering the likelihood and consequence of an event

27. In summary, natural climate variability and anthropogenic climate change are drivers of weather and climate-related hazards, and that a range of socioeconomic processes are drivers of vulnerability and exposure. This framing is useful as it highlights that vulnerability and adaptation is not only about the occurrence of a natural hazard, but is about all factors that can interact to increase or decrease risk. An assessment needs to consider how climate change may alter the natural hazards to which a population is exposed, whether exposures are likely to change with increasing climate change, and the characteristics of the sectors and populations exposed to the hazard that can increase their risk. A consideration of risk is needed to be able to identify how modifying policies and actions could reduce the burden of negative outcomes. Furthermore, a consideration of risk helps in screening and prioritizing the full range of options available for reducing flood and drought risks.

3. Hydraulic and Hydrological Considerations

28. The cause of flooding in Cambodia is not complex. However, the behaviour and impact of flooding has many dimensions and complexities. Some of the dimensions have positive consequences, while others have negative outcomes. To understand these consequences and outcomes requires an understanding of the hydraulic characterises and behaviour of the flood zones in Cambodia. A comprehensive study conducted by the Mekong River Commission (MRC) under the Flood Management and Mitigation Programme (FMMP) from 2011 to 2015 through the FMMP Initial Studies Project provided valuable insight

in how the flood zones behaved. The FMMP Initial Studies Project considered four climate change scenarios representing moderate, strong, extreme and drier climate projections for the assessment period of 2060. In addition to climate change, the study investigated upstream developments (dams) and future changes that would affect the hydrologic response of the basin. These changes included the development of new infrastructure, increased population, and changes to land-use associated with a higher standard of living. The assessment periods of 2030, 2060, and 2090 were selected. However, the design horizon for floodplain development plans was restricted to the year 2060. Therefore, for the assessments periods 2030 and 2090 only the moderate change climate scenario with no specific floodplain development plan was used. The FMMP Initial Studies Project addressed the impacts of these factors on future flood behaviour and flood risk in the Lower Mekong Basin.

29. It is well accepted that the characteristics of the floodplain affect flood behaviour and flood risk in the Lower Mekong Basin. The storage and conveyance features of the floodplain have a direct effect on flood levels, extent, duration, and timing of flooding. For the FMMP study, the floodplain was divided into Zones as adopted for WUP studies (WUP-JICA) but were modified slightly to give a more comprehensive coverage of the full extent of the influence of flooding from the Mekong in Cambodia and Vietnam. The Zones are shown in Figure 4.

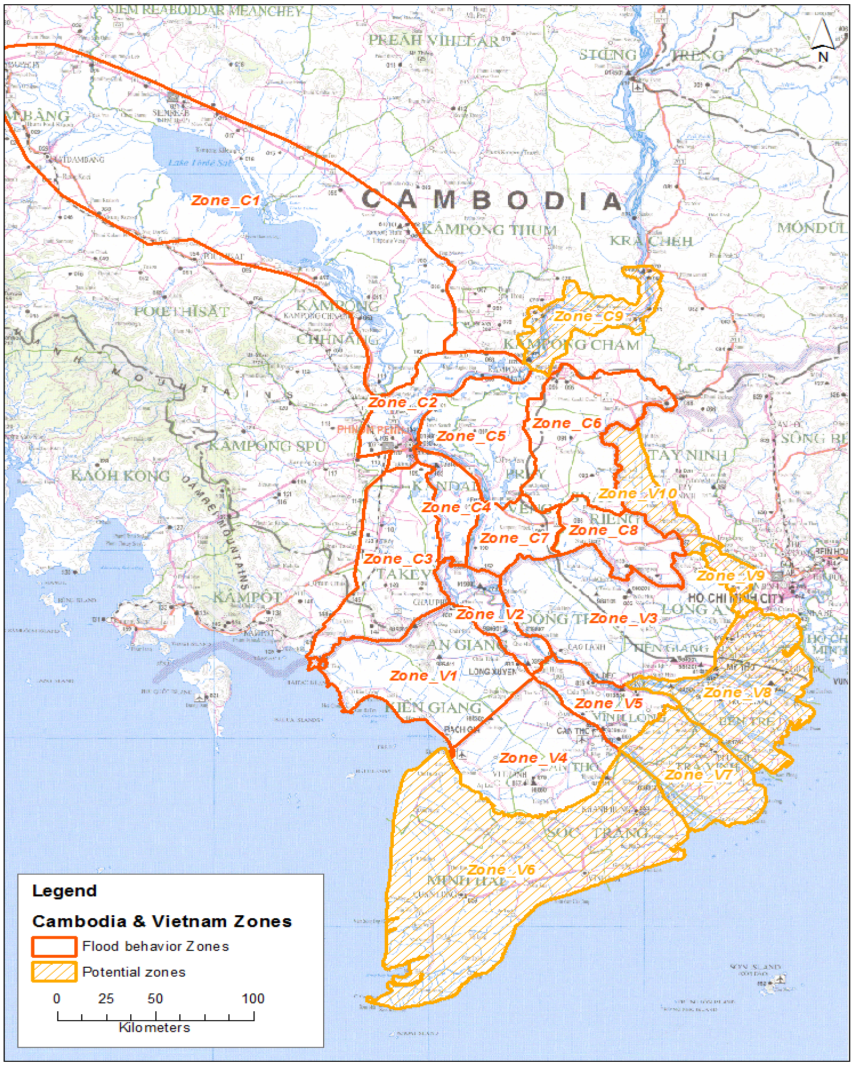

Figure 4: Flood Zones used by FMMP Initial Studies Project

3.1. Water Levels Implications

The FMMP Initial Studies Project modelled flows for key stations on the mainstream Mekong using Pearson Type III. The predicted changes in annual peak flows for 1:2 and 1:100 event and the percent change from the baseline flow was determined. The results are shown in Table 1.

Zone	Station Name	ARI	Annual Peak Flow Frequency in m^3/s							Percent Change from Baseline					
			BL 2014	CC-M 2030	CC-M 2060	CC-S-2060	CC-E-2060	CC-D-2060	CC-M 2000	CC-M 2030	CC-M 2060	CC-S 2060	CC-E 2060	CC-D 2060	CC-M 2090
C9	Kratie	2	45,598	46,756	48,016	55,375	62,958	38,651	52,649	102.5%	105.3%	121.4%	138.1%	84.8%	115.5%
		100	67,851	72,277	77,157	85,264	101,491	75,429	81,018	106.5%	113.7%	125.7%	149.6%	111.2%	119.4%
C9	Kampong Cham	2	41,458	41,840	42,864	49,905	56,287	35,766	46,326	100.9%	103.4%	120.4%	135.8%	86.3%	111.7%
		100	58,583	63,360	68,334	74,572	88,632	64,499	71,982	108.2%	116.6%	127.3%	151.3%	110.1%	122.9%
C2	Phnom Penh Chroy Changvar	2	34,981	35,352	35,962	38,623	40,090	32,154	37,302	101.1%	102.8%	110.4%	114.6%	91.9%	106.6%
		100	42,468	43,470	44,075	43,927	48,153	43,671	44,285	102.4%	103.8%	103.4%	113.4%	102.8%	104.3%
C4	Phnom Penh Chaktomuk	2	4,735	4,803	5,027	5,442	5,913	4,063	5,336	101.4%	106.2%	114.9%	124.9%	85.8%	112.7%
		100	5,883	6,038	6,127	6,849	7,637	5,750	6,378	102.6%	104.1%	116.4%	129.8%	97.7%	108.4%
C2	Prek Kdam (reversal flow)	2	(7,912)	(8,120)	(8,520)	(9,059)	(9,751)	(7,313)	(8,740)	103.8%	107.7%	114.5%	123.2%	92.4%	110.5%
		100	(12,238)	(12,467)	(12,131)	(12,681)	(12,992)	(12,728)	(12,731)	101.9%	99.1%	103.6%	106.2%	104.0%	104.0%
C4	Neak Leung	2	26,300	26,537	27,667	30,859	34,024	22,974	29,805	100.9%	105.2%	117.3%	129.4%	87.4%	113.3%
		100	34,758	36,081	37,010	40,130	43,741	31,830	38,234	103.8%	106.5%	115.5%	125.8%	91.6%	110.0%
C3	Koh Khel	2	3,498	3,515	3,641	3,917	4,158	3,059	3,857	100.5%	104.1%	112.0%	118.9%	87.4%	110.2%
		100	4,193	4,299	4,310	4,570	5,035	4,155	4,453	102.5%	102.8%	109.0%	120.1%	99.1%	106.2%
C1	Kampong Luong	2	5,614	5,778	6,125	6,502	7,334	4,605	6,141	102.9%	109.1%	115.8%	130.6%	82.0%	109.4%
		100	8,935	9,066	10,517	9,233	10,974	7,042	9,453	101.5%	117.7%	103.3%	122.8%	78.8%	105.8%
V1	Chau Doc	2	5,300	5,357	5,543	6,228	6,954	4,499	6,008	101.1%	104.6%	117.5%	131.2%	84.9%	113.4%
		100	6,931	7,050	7,321	8,543	10,323	6,267	7,871	101.7%	105.6%	123.3%	148.9%	90.4%	113.6%
V2	Tan Chau	2	22,856	22,980	23,771	25,728	27,292	20,365	25,117	100.5%	104.0%	112.6%	119.4%	89.1%	109.9%
		100	28,344	29,049	29,065	29,567	29,694	26,408	29,104	102.5%	102.5%	104.3%	104.8%	93.2%	102.7%

Table 1: Projected Annual Peak Flows for 1:2 and 1:100 event for the three selected Climate Change Scenarios

30. The sensitivity of mainstream sites to changes in peak flood flows and volume vary in space and with the frequency of event due to the characteristics of the channel and its associated floodplain. For Kratie in Zone C9 were flows are mainly restricted to the channel with limited floodplain capacity the 1:100 peak water levels are predicted to increase from 1.5 m to almost 4.0 m for 2060 depending on the climate scenario (Moderate, Strong, Extreme). In comparison to Phnom Penh were the floodplain has greater influence on attenuating the flood, the 1:100 peak water levels are predicted to only increase from 0.3 m to over 1.2 m for 2060 depending on the climate scenario.

31. It is important to note that the increase in water level is associated with the baseline water level for the selected return period. The specific channel and floodplain characterises may result in higher increases in water level for the more frequent events but theses have lower baseline water levels. Table 2 shows the increase in water level compared to the baseline at Phnom Penh. For 2060 and considering a 1:20 event, increases over the baseline water level are in the range of 0.3 m for the moderate scenario, 0.8 m for the strong scenario, and more than 1.3 m for the extreme scenario. Given the threshold of flooding is about 10 m AD (Above Datum) for the major urban area of Phnom Penh, the city has a level of protection against flooding from the river of 1:20 event with the existing flood protection infrastructure. The analysis suggests that this level of protection is not robust and by 2060 under the moderate change scenario and with no

further increase due to floodplain development the level of protection drops to the 1:10 event. For the strong scenario and extreme climate scenarios with significantly higher increases in 2060 flood peaks expected, flooding is expected to occur every 2-5 years without further flood protection work. The importance of this increase can not be underscored enough, given the potential for significant flood damages in Phnom Penh.

ARI	Baseline	CC-M 2030	CC-M 2060	CC-M 2090	CC-S 2060	CC-E 2060	CC-D 2060
2	8.70	0.07	0.35	0.79	0.93	1.50	-0.77
5	9.34	0.08	0.32	0.68	0.89	1.43	-0.74
10	9.66	0.10	0.30	0.62	0.86	1.38	-0.73
20	9.91	0.13	0.29	0.56	0.83	1.33	-0.72
50	10.19	0.18	0.28	0.49	0.80	1.27	-0.71
100	10.36	0.21	0.28	0.44	0.77	1.23	-0.70

Table 2: Increase in water level at Phnom Penh above the baseline with different return periods for each of the selected Climate Change Scenarios

32. The FMMP Initial Studies Project assessed changes in water levels on the floodplain for a number of districts in each of the floodplain zones. The changes in water level compared to the baseline are shown for the various floodplain zones for a 1:100 event for the respective climate change scenarios for the year 2030, 2060, and 2090. The "moderate" scenario for the year 2030 shows an increase in maximum water level between 0.1 and 0.2 m at most locations. For the "moderate" scenario for the year 2060 and 2090, the typical increase in water level ranges from 0.2 to 0.4 m and 0.3 to 0.6 m respectively. The "strong" scenario shows higher values in water level for the year 2060, with an increase of 0.4 to 1.0 m. For the "extreme" scenario the increase in water level is expected to be 0.6 to 1.6 m. The "dry" scenario shows a decrease in water level of 0.2 to 0.8 m for the year 2060. The details for each of the scenarios, for the periods 2030, 2060, and 2090, for key locations by floodplain zones with respect to a 1:100 event, are shown in Table 3.

33. In summary, there is a modest increase in water level relative to the normal rise in the flood season depending on the climate change scenario considered. In some floodplain zones rises are much more significant and the consequences of even a 0.5 m rise, should it overtop a defence for example, could be catastrophic. The most change in water level occurs in the more confined sections of river for example Kratie to Kampong Cham reach. There is the potential for additional spill across the Cambodian floodplains to cause a rise in water level and flood frequency for the floodplain Zones V9 and V10 in Viet Nam.

Return Period		100						
Cambodia								
			2030-M	2060-M	2090-M	2060-S	2060-E	2060-D
Zone	Town/District Name	BL2014	Change	Change	Change	Change	Change	Change
C1	Bac Prea	10.45	0.08	0.31	0.48	0.87	1.54	-0.83
C1	Kampong Chhnang	10.43	0.08	0.31	0.50	0.89	1.56	-0.83
C1	Kampong Thom	10.44	0.08	0.30	0.50	0.88	1.55	-0.83
C2	Peam Chikang	14.56	0.30	0.39	0.34	0.43	0.69	-0.52
C2	Svay Ampear	10.66	0.30	0.49	0.70	1.10	1.74	-0.69
C3	Angkor Borei	5.11	0.09	0.24	0.49	0.75	1.50	-0.36
C3	Bati	8.91	0.17	0.20	0.31	0.46	0.70	-0.43
C3	Borei Cholsar	4.50	0.09	0.20	0.49	0.74	1.35	-0.37
C3	Doun Keo	4.48	0.17	0.27	0.55	0.83	1.44	-0.26
C3	Kaoh Andaet	4.50	0.08	0.19	0.47	0.73	1.32	-0.37
C3	Kiri Vong	3.50	0.09	0.38	0.81	1.13	1.80	-0.14
C3	Prey Kabbas	5.66	0.12	0.27	0.53	0.79	1.59	-0.34
C3	Treang	4.56	0.08	0.19	0.48	0.75	1.36	-0.38
C4	Kandal Steung	8.91	0.18	0.20	0.32	0.49	0.79	-0.43
C4	Kien Svay	6.67	0.15	0.30	0.67	1.79	4.22	-0.27
C4	Koh Thum	6.30	0.08	0.19	0.46	0.70	1.22	-0.41
C4	Lvear Em	9.90	0.22	0.28	0.44	0.74	1.15	-0.69
C4	S'ang	7.69	0.06	0.08	0.19	0.35	0.85	-0.29
C4	Ta Khmau	9.39	0.06	0.13	0.19	0.35	0.62	-0.53
C5	Ba Phnum	7.04	0.18	0.30	0.46	0.62	0.96	-0.45
C5	Mesar Brachan	11.72	0.20	0.30	0.26	0.27	0.44	-0.16
C5	Peam Ro	8.39	0.19	0.25	0.40	0.59	0.86	-0.64
C5	Prey Veng	10.74	0.07	0.10	0.15	0.10	0.38	-0.10
C6	Mesang	6.75	0.14	0.23	0.34	0.46	0.73	-0.34
C6	O RaingOv	13.85	0.28	0.44	0.41	0.50	0.77	-0.47
C7	Kampong Trabaek	5.80	0.14	0.31	0.49	0.67	1.04	-0.51
C7	Leuk Daek	7.50	0.16	0.19	0.31	0.47	0.66	-0.54
C7	Peam Chor	7.06	0.15	0.16	0.27	0.42	0.59	-0.50
C7	Preah Sdach	5.78	0.11	0.21	0.42	0.63	1.20	-0.22
C8	Kampong Rou	3.82	0.10	0.24	0.48	0.73	1.23	-0.45
C8	Svay Chrum	4.96	0.14	0.36	0.64	0.90	1.37	-0.32
C8	Svay Rieng	4.91	0.10	0.23	0.46	0.70	1.23	-0.28
C9	Bos Leav	23.89	0.74	1.42	1.87	2.21	3.94	-0.55

Table 3: Projected changes in water level for a 1:100 event for Floodplain Zones C1 to C9 (Cambodia)

3.2. Changes in Sea Level

34. The FMMP Initial Studies Project investigated the influence of expected sea level rise due to climate change. The range of sea level rise resulted from an analysis of GCM results for the Viet Nam coast and were found to closely follow those used by Viet Nam. The sea level rise is expected to approach 0.5 m by 2060 and 1.0 m by 2090 for RCP8.5. Figure 5 shows the results of the investigation as the expected increase in peak flood level for a 5% to 20% increase in flow and for a sea level rise of 0.5 m and 1.0 m. The results demonstrate that sea level rise will have significant implications even under a climate scenario with a small increase in flood flows.

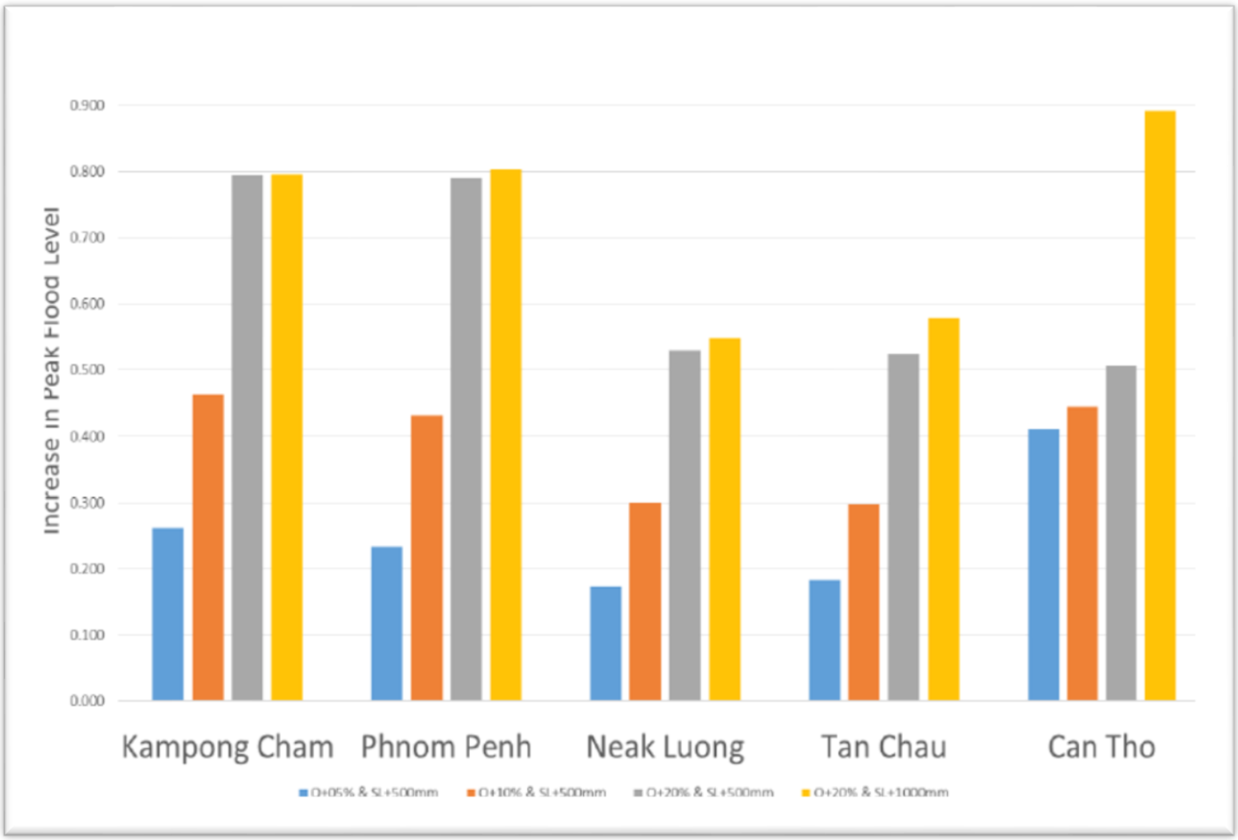

Figure 5: Sensitivity on peak flood levels for flow increases of 5%, 10% and 20% with a sea level rise of 0.5 m and flow increase of 20% with a 1.0 m sea level rise

3.3. Flood Duration Implications

35. The FMMP Initial Studies Project also investigated the climate change implications on the duration of flooding. The analysis assumed that 'normal flooding', defined as a 1:2 year event, is unlikely to cause damage and indeed may have benefits for fisheries, flushing of acid soils, and the deposition of nutrient rich sediments. Therefore, the analyses considered the duration above a 1:2 year peak. The FMMP study assessed duration of flooding for each Zone.

36. The main floodplain areas in Cambodia experience similar flood durations. Overall the longest duration of flooding is in the Tonle Sap Lake area. Figure 6 shows duration of flooding above 1:2 year peak level for the baseline period.

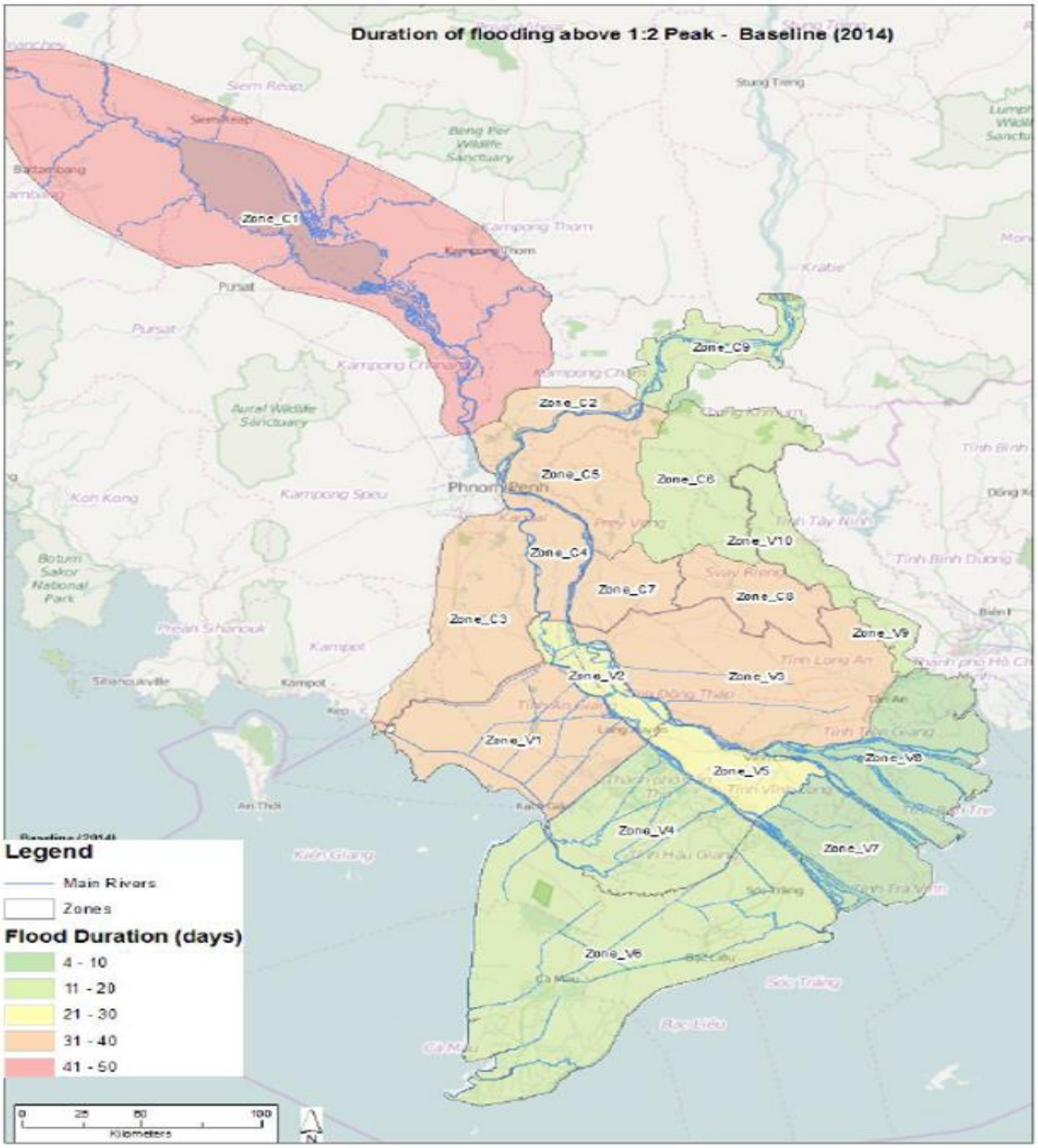

Figure 6: Duration of Flooding above 1:2 year peak water level

37. The FMMP study calculated changes in duration of flooding as well as onset and end dates for each of the climate scenario. The results are shown in Table 4. The "moderate" scenario for the year 2030 shows an increase in flood duration between 1 and up to 7 days at most locations. For the "moderate" scenario for the year 2060 and 2090, the typical increase in flood duration approaches 14 days and 21 days respectively. The "strong" scenario shows flood duration values for the year 2060 increase by three weeks and the increase approaches four weeks for some Zones. For the "extreme" scenario flood duration is predicted to increase up to five weeks by 2060. The "dry" scenario shows a significant decrease in flood

duration with some Zones experiencing limited flooding and others having only 7 to 10 days of flood duration for the year 2060. The changes in duration of flooding will be significant for floodplain based agriculture, affecting planting and harvesting dates.

			Change in Duration (Days)					
Zone	Town/District Name	BL 2014	CC-M 2030	CC-M 2060	CC-S 2060	CC-E 2060	CC-D 2060	CC-M 2090
C1	Bac Prea	48	7	12	22	32.5	-33	17
C1	Kampong Chhnang	48	6	12	23	32.5	-33	17
C1	Kampong Thom	48	6	12	22	33	-33	17
C2	Peam Chikang	20	1	-1	18	30	-6	10.5
C2	Svay Ampear	41.5	2	8	18	28.5	-23.5	20.5
C3	Angkor Borei	40	14	10	26	38	-18	24.5
C3	Bati	36	7	10	24.5	36	-22.5	26
C3	Bourei Cholsar	41	9.5	14	28	39	-14	27
C3	Doun Keo	42.5	10.5	10	25.5	36.5	-18.5	24.5
C3	Kaoh Andaet	41	9.5	14	28.5	39	-14	27
C3	Kiri Vong	40	8.5	16	29.5	41.5	-13.5	27
C3	Prey Kabbas	39	12	9.5	25	37.5	-20	24
C4	Kandal Steung	36	7	10	24.5	36	-22.5	26
C4	Kien Svay	83	-24	-1.5	11	21.5	-79	46
C4	Koh Thum	39	13	10	25.5	37	-20	24
C4	Lvear Em	39	3	8	20	29.5	-25	22
C4	S'ang	36	6	10	25	36	-22.5	26
C4	Ta Khmau	39	1	8	20.5	30	-25	21
C5	Ba Phnum	40.5	4.5	9	19.5	28.5	-27	22.5
C5	Mesar Brachan	23	1	-0.5	21	30	-8	11
C5	Peam Ro	41.5	1	5.5	18.5	28.5	-32.5	20.5
C5	Prey Veng	20	6	11	28	40	-2.5	19.5
C6	Mesang	40.5	1.5	6.5	20	29.5	-29.5	22.5
C6	O RaingOv	22	0	-1	17	28	-9.5	9
C7	Kampong Trabaek	40.5	6.5	6.5	20	31	-26.5	22.5
C7	Leuk Daek	41.5	2.5	6	19.5	30	-28.5	21.5
C7	Peam Chor	42	3.5	5.5	19	29.5	-28	22
C7	Preah Sdach	42	7	6	19.5	30	-26	22
C8	Kampong Rou	42	4	12	22.5	35	-22	25
C8	Svay Chrum	39	11	14	25	35.5	-27	24.5
C8	Svay Rieng	38	12	11.5	24	35	-28	24.5
C9	Bos Leav	17	2.5	1	10	20.5	-9.5	6.5

Table 4: Change in flood duration above 1:2 year peak for various climate scenarios

3.4. Changes in Conveyance on the Floodplain

38. The FMMP Initial Studies Project investigated changes in conveyance on the floodplain. The measurement of conveyance on the floodplain is complex situation in the Lower Mekong basin given that rapid changes can go into storage and attenuate peak flows out of a Zone. The proportional changes in flood flows are generally larger on the floodplains than the change in the main rivers where there is capacity available. For example, there can be dramatic increases when a threshold is exceeded due to a

road or bank being overtopped. This effect is shown in Figure 7 for the 2060 strong and extreme climate change scenario. The flood culverts on the boundary between zone C2 and C1 are inadequate for the increased flow and the road is eventually overtopped resulting in a dramatic increase in flood flow.

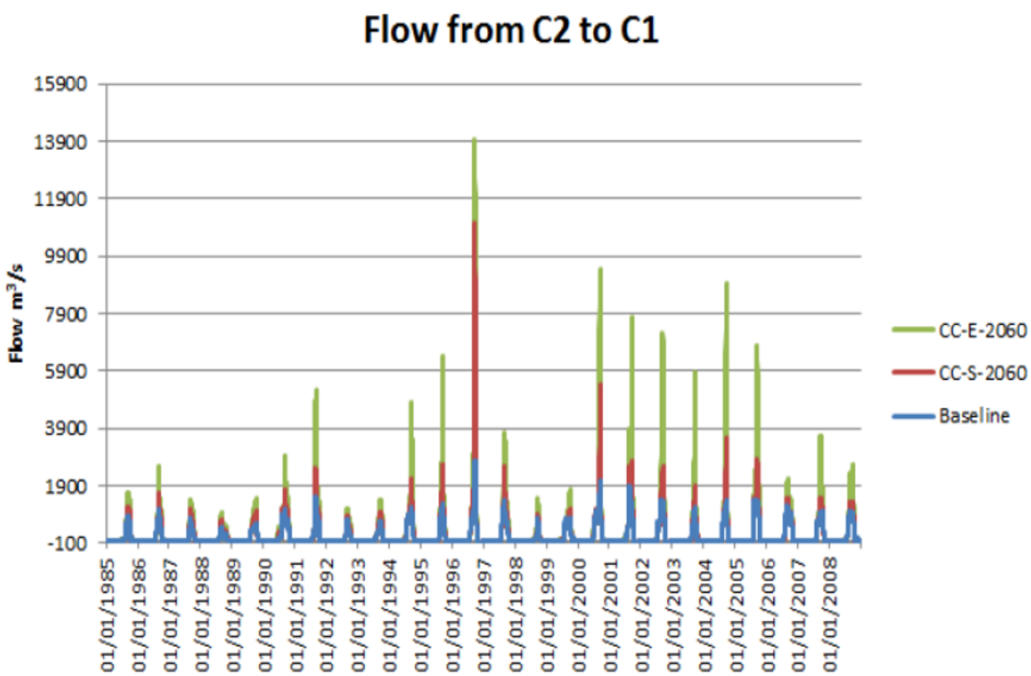

Figure 7: Change in floodplain conveyance due to thresholds being overtopped

39. In Cambodia, the Mekong left and right banks are both large conveyors of flood waters above Phnom Penh. Below Phnom Penh the left bank (east side) becomes the dominant conveyor and the Trans Bassac and the area west of the Bassac convey less flood water. It has been observed that new infrastructure such roads in Cambodia have reduced conveyance flows on the floodplain.

3.5. Changes in Flood Extent

40. The FMMP Initial Studies Project studied the change in flood extent for the Great Lake from the baseline 100-year water level and the change expected for the extreme climate change scenario. The study found that, although the change in lake is small (only 2.5 km^2) relative to the total flood extent, damages could increase greatly as new areas that previously have been safe would be under threat. The FMMP study shows that the future extreme flood extent encroaches on the urban areas of Battambang and Siem Reap, which would have serious implications as the urban areas increase due to development.

3.6. Changes in Flood Storage

41. The FMMP Initial Studies Project assessed the amount of flood storage in each Zone. The floodplain storage by Zone is shown in Table 5. The assessment showed that flood storage dominated by the Tonle Sap lake. For comparison Nam Theun 2 reservoir in Lao PDR has a maximum storage capacity of 3.53 km^3 or 3530 MCM about the same as the flood volume stored in Zone C2 or less than 3% of the floodplain

storage on Floodplain. The large Chinese Dam such as Xioawan has a capacity of 15,000 MCM or less than 12% of the total floodplain storage estimate.

Zone	Maximum Floodplain Storage for Baseline Period 1984 to 2008 MCM	Proportion of Total
C1	71,129	75.0%
C2	3,729	3.9%
C3	3,206	3.4%
C4	1,720	1.8%
C5	8,607	9.1%
C6	907	1.0%
C7	1,987	2.1%
C8	912	1.0%
C9	2,699	2.8%
Total	**94,898**	**100%**

Table 5: Maximum floodplain storage during baseline period

42. The FMMP study calculated the maximum floodplain storage utilised in each climate scenario as shown in Table 6. The changes in storage follow a similar pattern to water level change with a maximum of 25% more storage in the extreme climate scenario and a reduction of 18% in the drier climate scenario for 2060.

Zone	Baseline (2014)	CC-M 2030	CC-M 2060	CC-S 2060	CC-E 2060	CC-D 2060	CC-M 2090
C1	71,129	72,487	77,383	82,352	93,081	61,135	81,464
C2	3,729	4,191	4,622	5,627	6,436	4,029	4,945
C3	3,206	3,326	3,676	4,346	5,835	2,872	4,082
C4	1,720	1,803	1,961	2,346	2,935	1,539	2,137
C5	8,607	9,114	9,699	10,764	12,129	8,339	10,171
C6	907	1,014	1,129	1,300	1,471	889	1,217
C7	1,987	2,140	2,416	2,869	3,654	1,781	2,697
C8	912	1,001	1,235	1,529	2,002	787	1,417
C9	2,699	2,905	3,098	3,680	4,256	2,983	3,283
Total	**94,898**	**97,981**	**105,219**	**114,813**	**131,799**	**84,354**	**111,413**

Table 6: Maximum floodplain storage volume under various climate scenarios

43. The FMMP Study investigated the implications on floodplain storage of expansion of urban areas considering projected population migration and increases as well as loss of floodplain due to flood protection and encroachment on to the floodplain. The development scenarios were:

- Urbanisation of Phnom Penh and Kampong Cham to maximum extent projected for 2090
- Scenario 1 plus 50% loss in floodplain storage on the Mekong left bank
- Scenario 2 plus 50% loss in floodplain storage on Mekong right bank and Tonle Sap river

- Scenario 3 with 50% loss in floodplain storage in Trans Bassac and Bassac right bank
- Scenario 4 with 75% loss in floodplain storage
- Scenario 5 with Tonle Sap Great Lake confined to dry season extent

44. The simulation used the 2011 flood year, which was a 1:10 to 1:20 flood year, to determine the expected change in water levels for each development scenario from the 2011 flood levels. The simulation did not allow for a probabilistic analysis but did give the direction and order of magnitude of the expected change in water level due to floodplain development. The simulation results at key locations are shown in Table 7.

Location	Development Scenario					
	Urbanization	Urbanization plus 50% loss on left bank	Urbanization plus 50% loss on left and right banks	Urbanization plus 50% loss of all floodplain storage	Urbanization plus 75% loss of all floodplain storage	Urbanization. 75% loss of all floodplain storage, and Tonle Sap Lake confined to dry season extent
Kratie	0.01	0.01	0.14	0.14	0.16	0.19
Kampong Cham	0.08	0.08	0.86	0.88	0.96	1.12
Phnom Penh Port	0.17	0.16	0.35	0.39	0.46	1.45
Prek Kdam	0.09	0.08	0.18	0.22	0.28	1.41
Kampong Luong	0.13	0.12	0.18	0.22	0.28	1.43
Neak Luong	0.06	0.06	0.18	0.23	0.29	0.83
Koh Khel	0.45	0.44	0.57	1.06	1.05	1.60

Table 7: Expect change in flood level from the 2011 flood level for various development scenarios

45. The results show that the main river stations closest to the floodplain loss areas are the most affected. For example, Kampong Cham, Phnom Penh, and Koh Khel are significantly affected by the loss of floodplain and conveyance. The large increases in flood levels at all stations for Scenario 6 demonstrates the importance of the Tonle Sap Great Lake storage. As well, it is important to note that some locations show a large rise due to loss of floodplain storage. Once the floodplain storage is lost, water levels rise close to those in the main river.

4. Flood and Drought Mitigation Strategies and Measures

46. The FMMP study of the Cambodian floodplain and Mekong delta highlighted the role of the floodplain in terms of conveying and attenuating flood flows. Floodplain storage is seen to be critical as a naturally functioning part of the river system that helps to reduce flood levels and downstream affects. Accordingly, changes on the floodplain as well as climate change will have significant implications leading to higher flood water levels, longer duration of flooding, and increased flows. It is apparent that the floodplain system with

the current infrastructure cannot absorb the increases in extreme floods that most of the climate scenarios indicate. The relative fragility of the flood control system for cities such as Phnom Penh and secondary towns such as Kampong Cham are highlighted by the results of the FMMP study.

4.1. National Strategies

47. The Cambodian government has taken a multi-dimensional approach to flood and drought management. The approach uses both structural and non-structural measures to manage the risk and effects of floods and droughts. A National Early Warning Strategy and a Standard Operating Procedure (SOP) for the Flood Early Warning System was drafted in 2014 for the Cambodian National Committee for Disaster Management by the Asian Disaster Preparedness Centre through funding by the World Bank. The strategy addressed the need to conduct risk assessments and to develop early warning systems and building codes. The SOP for the flood early warning system defined the roles and responsibilities of the various government agencies involved in flood response.

48. Under the GMS Flood and Drought Risk Management and Mitigation Project (GMS-FDRMMP), a SOP for the flood management at the commune level was developed as well as a complementary SOP for drought management, which are both based on the 2014 National Early Warning Strategy. The GMS-FDRMMP is also addressing strategies for improved and more effective communications of flood and drought events at the community level.

49. The National Early Warning Strategy and SOPs have been prepared from the perspective of how to respond to floods and droughts once they occur. Guidance and processes from the perspective of preparedness and adaptation are lacking as well as the development of standardizes building codes and land use zoning is limited. However, the limited availability of the standardized building codes, land zoning, and adaptation polices has not prevented the Cambodia government from undertaking structural measures to provide improved flood protection for larger centres and important transportation routes. Efforts to address drought events have been more difficult. Water retention and storage have been the predominate strategies used to date.

50. It is important to note that the Mekong floodplain and the Tonle Sap Great Lake system provides a critical flood attenuation and a drought mitigation function, which must be critically considered when developing flood and drought preparedness and adaptation strategies. Unplanned and uncontrolled development that threatens the storage capacity of the floodplain or the loss of flood conveyance will have long-terms consequences for efforts to reduce damages.

4.2. Structural Protection Measures

51. The most effective flood protection methods in Cambodia are relocation and elevation. However, when these methods are not feasible, structural flood proofing methods may be an alternative. Flood proofing is defined as any combination of structural and non-structural measures, which reduce or eliminate damages and loss caused by floods and droughts. Structural measures aim to reduce flood risk by controlling the flow of water. Structural measures range from engineered structures, such as flood defences and drainage

channels to more natural and sustainable complementary or alternative measures such as wetlands and natural buffers. However, structural measures can be overtopped by events beyond their design capacity and result in significant damage and loss. As well, structural measures transfer flood risk by reducing flood risk in one location only to increase it in another location. Structural solutions have a high upfront investment cost, may induce complacency by their presence, and can result in a significant increase in damages if they fail.

52. Structural measures to address floods and droughts in Cambodia are typical focused on protection measures such as dams, dikes, and levees, and transportation corridor improvements by raising the elevation of road and rail lines. Building construction in urban areas is most often not flood proofed, whereas in rural areas it is common to have elevated living quarters. Structural measures related to droughts include reservoirs, flood water retention ponds, rainwater harvesting, irrigation, and wetland restoration. A number of flood and drought structural measures are shown in Table 8.

Strategy	Options
Reduce Flood Susceptibility	Dams and reservoirs
	Dikes, levees, and flood embankments
	High flow diversions
	Channel improvements
	Flood proofing
	Location of facilities
	Wetland Restoration
Reduce Drought Susceptibility	Dams and reservoirs
	Water retention ponds
	Irrigation
	Groundwater Use
	Wetland Restoration

Table 8: Typical Flood and Drought Structural Measures

4.3. Non-Structural Protection Measures

53. Non-structural measures are actions taken to mitigate flood and drought loss and damages through better planning and management of watershed development. Non-structural measures address flood and drought risks by building the capacity of people to cope with floods and droughts. As such, building capacity and awareness are key components of a non-structural flood and drought mitigation and risk reduction strategy. Non-structural measures include activities such as having in place an early warning system, building and zoning codes, supportive policies and strategies, education and awareness initiatives,

and institutional capacity. Non-structural measures do not usually require large upfront investments, but rely on an improved understanding and awareness of floods and droughts, on an adequate forecast system, and on the affect population taking appropriate actions. Non-structural measures have four main functional elements as shown in Figure 8.

54. **Risk Knowledge** – Knowledge of the risk is gained through the conduct of risk assessments. The assessment of risk requires the systematic collection and analysis of data and considers the dynamic nature of flood and drought events and their associate vulnerabilities that arise from processes such as urbanization, rural land-use change, environmental degradation, and climate change. Risk assessments and risk maps help to prioritize flood and drought actions and to guide preparations for prevention, mitigation, and response.

Figure 8: Elements of Non-Structural Measures

55. **Monitoring and Warning** - Warning services lie at the core of the flood and drought mitigation system. There must be a sound scientific basis for predicting and forecasting flood and drought events and a reliable forecast and warning system. Continuous monitoring of flood and drought event parameters is essential to generate accurate warnings in a timely fashion. Warning services for flood and drought events must be coordinated and benefit from existing institutional, procedural, and communication networks.

56. **Dissemination and Communication** - Clear messages containing simple and useful information is critical in enabling proper responses from those at risk as well as to agencies responsible for flood and drought response and relief. Regional, national, and community level institutions must be identified and appropriate roles and responsibilities established well before any events occurs.

57. **Response Capability** - It is essential that communities understand their risks, respect the warning service, and know how to react. Education and preparedness programs play a key role. It is also essential that flood and drought management plans be in place, well-practiced, and tested. Communities should be well informed on options for safe behaviour, available evacuation routes, and how best to avoid damage and loss to property and life.

58. Non-structural measures in Cambodia are continuing to evolve. Cambodia has a good understanding of the risk dimension and a number of risk assessments have been undertaken for floods, however few have considered droughts. Many of the studies advocate a 'living with the flood' strategy verse a structural

approach. Forecasting and warning capacity is continuing to improve as well as the approach to communicate warnings and disaster information continues to improve and evolve to reach the community level much quicker. Mobile communications technologies and services is facilitating this change. The area requiring the greatest attention is awareness and appropriate response at the community level to flood and drought warnings. However, the level of awareness and knowledge of appropriate responses is expected to increase significantly and in a short period of time as communications of the flood and drought conditions become more timely and comprehensive. A number of flood and drought non-structural measures are shown in Table 9.

Strategy	Options
Reduce Flood and Drought Susceptibility	Catchment management
	Flood plain regulation
	Development and redevelopment policies
	Design and location of facilities
	Housing and building codes
	Flood and drought forecasting and warning
	Greater reliance on groundwater
	Drought tolerant crops
	Restoration of wetlands
Mitigate Impacts of Floods and Droughts	Information and education
	Disaster preparedness
	Post flood and drought recovery
	Flood and drought insurance
Preserve the Natural Capacity of Flood Plains	Flood plain zoning and regulations
National Flood and Drought Strategies	Coordination between governments and non-government organizations at national, provincial, and local levels

Table 9: Typical Flood and Drought Non-Structural Measures

4.4. Integrated Flood and Drought Management

59. Integrated Flood and Drought Management or Sustainable Flood and Drought Management integrates land and water resources development from a basin perspective within the context of an Integrated Water Resources Management (IWRM) approach. The intent of the approach is to maximize the efficient use of floodplains, wetlands, and upland forested areas and to minimize the loss to life and livelihoods. Flood and drought management within the context of IWRM must consider socio-economic activities, land-use patterns, hydro-morphological processes, structural and non-structural approaches, and institutional

capacity. A Sustainable Flood and Drought Management approach combines land use planning, water management, and social-economic development under a comprehensive plan. Land use is directly linked to social-economical-environmental development, which in turn affects both water quantity and quality. Therefore, changes in land use can drastically change the characteristics of floods, droughts, and the associated water quality and sediment transport.

60. Although a Sustainable Flood and Drought Management approach will not be considered at this time given the complexities of the approach and the need for significant institutional capacity, it is presented here for completeness of the discussion of flood and drought protection measures and may offer a long-term goal for flood and drought management in Cambodia. Figure 9 provides a graphical presentation of the concept of Sustainable Flood and Drought Management.

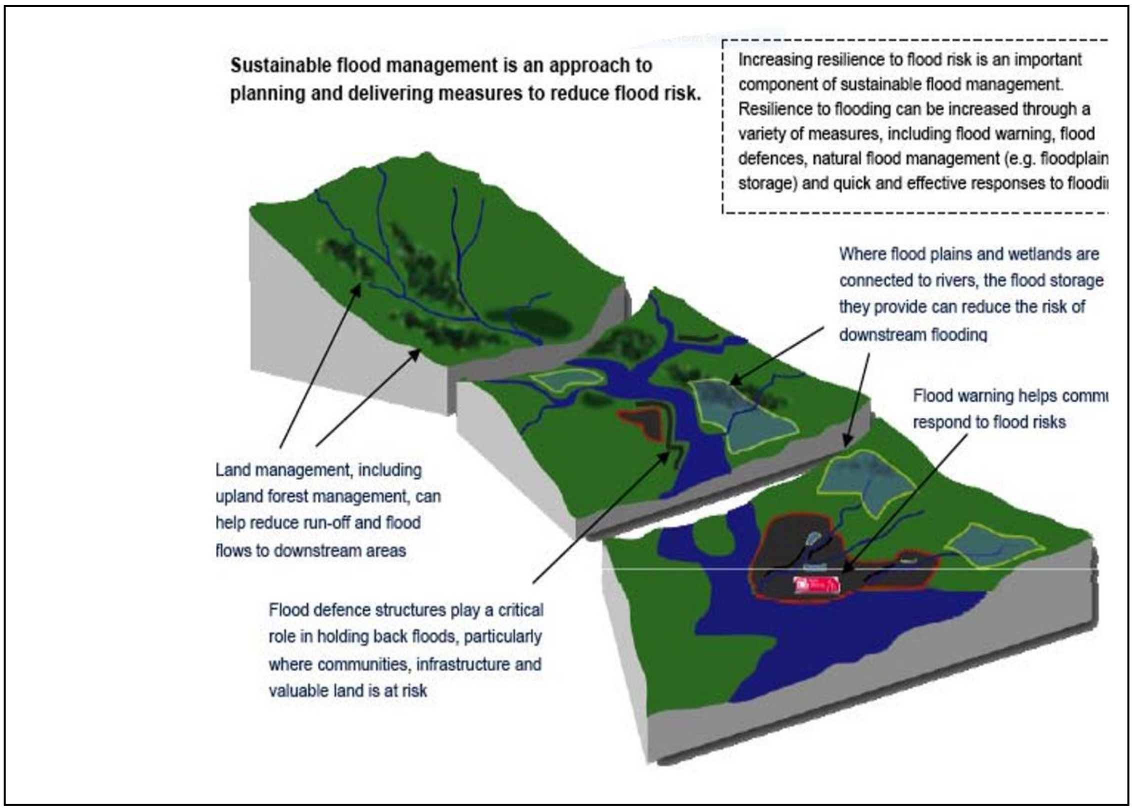

Figure 9: Sustainable Flood and Drought Management

5. Residual Risk Associated with Protection Measures

61. A risk based approach to the assessment of natural disasters considers the probability of a natural disaster occurring and the consequences or level of damages that are expected. Furthermore, the risk-based approach considered the concept of inherent risk and residual risk as a dimension of the risk assessment. Inherent and residual risk reflects whether risk controls are in place when assessing the consequences associate with a natural disaster. For example; for a selected level of flooding if controls are

in place to address the flooding at the time of assessment, then the measure of risk is considered to reflect a residual risk. The concept of inherent and residual risk is further demonstrated in Figure 10 for a range of flood mitigation and adaption strategies. The figure shows how the initial risk or inherent risk is reduced through a number of non-structural and structural measures. A similar risk base approach can be applied when considering drought mitigation and adaptation strategies.

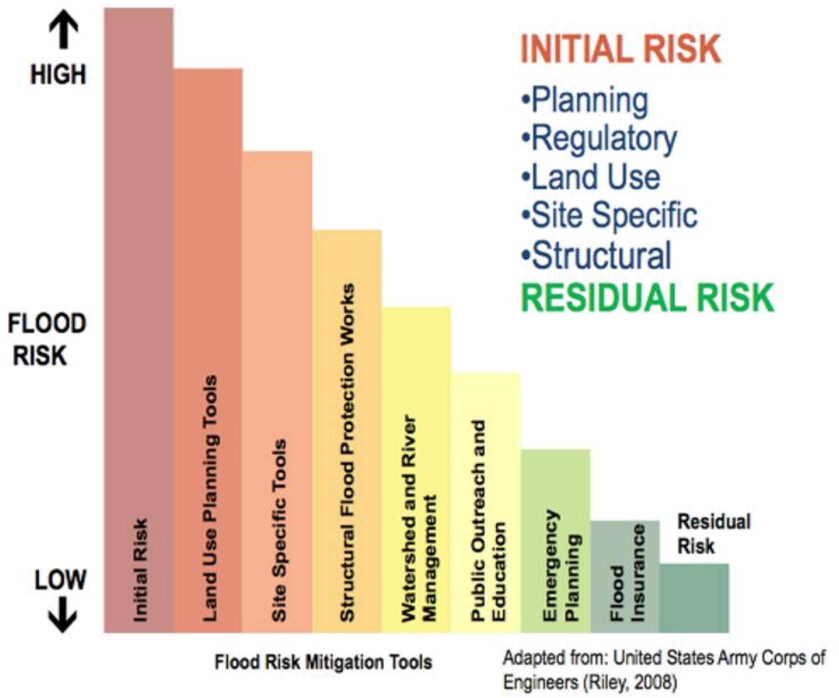

Figure 10: Residual risk considering non-structural and structural mitigation and adaptation measures

62. Conducting risk assessments to understand the devastating impact that floods and drought can have on property, the environment, and human lives makes clear the importance of effective flood and drought risk management in fostering community preparedness and resiliency. Changing climatic conditions present a source of uncertainty that complicates the flood and drought assessment process.

63. Flood risk assessment refers to the quantitative analysis of the level of flood risk for a river reach or basin. The identification and mapping of flood risks requires information on flood hazard such as the extent and duration of flooding and the level of vulnerability in the area affected by flooding. Flood hazard analysis involves an analysis of flood occurrence, which considers meteorological events that may lead to flooding. As well, hydrological information such as peak discharges and volumes, as well as the characteristics of the river channel and floodplain are used to define flood events and flood extent. The flood hazard is defined in terms of inundation area, height of water, water velocity, and duration considering meteorological, hydrological, river channel, and floodplain characteristics. The level of risk is also related to the probability that a flood event of a specific magnitude will occur. Vulnerability and damage assessment requires an analysis of potential damages based on socio-economic-environmental data for the flood prone

area. This information is used to build a vulnerability/damage model. Risk determination and flood risk mapping involves the determination of risk by combining the results of the flood hazard analysis for an associated probability of occurrence and the results of the vulnerability/damage assessment. The results can be displayed as risk maps, graphs, or risk numbers. The results provide an expected level of loss with an associated probability or frequency of occurrence. The process for conducting a risk assessment is shown by Figure 11.

64. Drought risk assessment is generally more difficult to quantify and can vary depending on the type of drought, which can be defined as:

- Meteorological drought, which is defined by low rainfall over the wet season (May to November).
- Hydrologic drought, which is described by relatively low amounts of water carried by rivers and streams, which can be the result of climatological conditions (low precipitation and high temperatures).
- Agricultural drought, which considers the effect of the reduced availability of soil moisture on crop yields, whether for food or fodder.

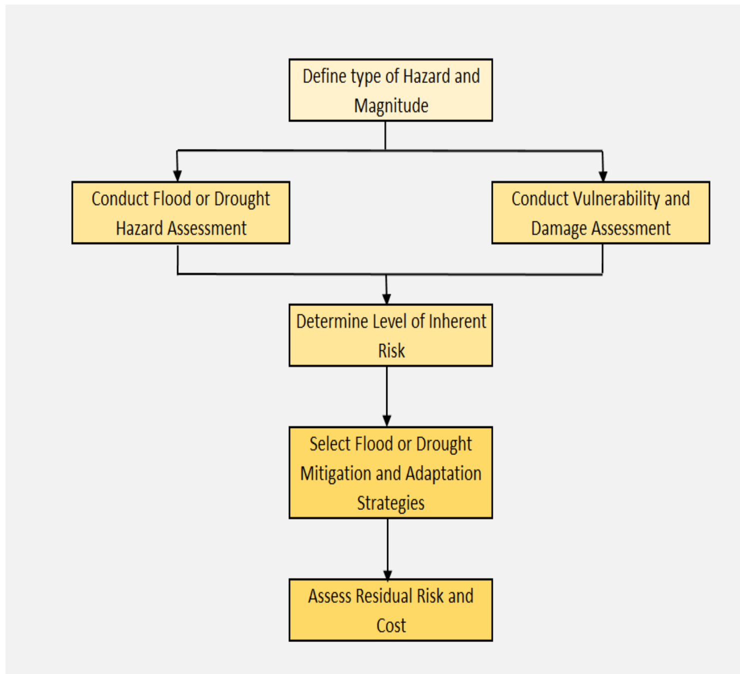

Figure 11: Risk assessment process

65. Meteorological, hydrological, and agricultural droughts are typically assessed through the analyses of a time-series of variables such as rainfall, stream flow, groundwater levels, and soil moisture data, on a variety of time scales. Drought is characterized by its intensity, duration, and spatial coverage. Intensity refers to the degree of the precipitation shortfall and the severity of impact associated with the shortfall. It is generally measured by the departure from normal and is closely linked to duration in the determination of impact. Another distinctive feature of drought is its duration. Droughts usually require a minimum of two to three months to become established, but then can continue for months or even years. The magnitude of drought is closely related to the timing of the onset of the precipitation shortage, its intensity, and the duration of the event. Droughts also differ in terms of their spatial characteristics which can affect different areas from season to season. If the weather pattern persists for a short time over a few weeks or a couple months, the drought is considered short-term. But if the weather pattern becomes entrenched and the precipitation deficits last for several months to several years, the drought is considered to be a long-term drought. Often a drought index is used to display the severity and extent of droughts. Similar to flood risk assessment, drought risk

assessment requires and understanding of the potential damages based on socio-economic-environmental data for the drought affected area. This information is used to build a vulnerability/damage model. Risk determination and drought risk mapping involves combining the results of the drought index analysis and the results of the vulnerability/damage assessment. The results can be displayed as risk maps, graphs, or risk numbers. The results provide an expected level of loss with an associated probability or frequency of occurrence.

66. The availability of vulnerability and damage information for floods and droughts at a disaggregated level is limited. Damage and loss information are often only available at an aggregate level making it difficult to develop damage inundations curves for specific areas of interest. As well, the damage or loss due to floods and droughts are often not disaggregated into categories of agricultural, housing, infrastructure, and relief. Lower magnitude floods have significant benefit to the aquatic and natural environment based economic and social functions. Floods are seen as a natural process for nutrient distribution and enrich of agricultural soils. These benefits can often offset damages for the more frequently occurring floods. Given this limited availability of damage and loss data at disaggregated level makes the conduct of a cost and potential benefits analysis of proposed flood and drought measures a challenging task.

6. Conclusions and Recommendations

67. Cambodia is vulnerable to flooding and drought events as much of the population depends upon subsistence agriculture for their livelihood. As a result, people frequently suffer hunger, increased poverty, or even the loss of life when such natural disasters occur. The National Committee for Disaster Management estimates the exposure to flood risks in terms of GDP in Cambodia is at 14%, which is the highest among the Lower Mekong Basin countries. Cambodia also has the highest loss of life per flood event, 87 people on average. The average number of people affected per flood event is 733,355, highest among the four riparian countries of Lower Mekong Basin countries. Comprehensive statistics on drought impacts are limited for Cambodia. However, it is widely acknowledged that drought is one of Cambodia's most significant and widespread natural hazard. Within the past 25 years there have been a significant number of distinct drought events: 1986-87, 1994, 1997-98, 2002, 2004, 2005, 2012, 2014, and 2015-16. The 2004 drought event affected two million people in fourteen provinces with a total damage estimated at USD 21 million, according to the National Committee for Disaster Management's Flood and Drought Bulletin (2004). In contrast, the Cambodian floodplain including the Tonle Sap Great Lake form the most productive part of the Mekong Basin and support the highest population densities with over two thirds of Cambodia's 15 million people or over 10 million people earning a livelihood in this flood and drought prone area.

68. The Cambodian floodplain and the Tonle Sap/Great Lake system provides a critical flood attenuation function that is potentially threatened by floodplain development and loss of flood conveyance due to infrastructure and urban encroachment. The loss of the natural flood attenuation function through development on the floodplain can have significant consequences for increasing flood levels and duration.

As well, the benefits of a natural flood cycle to fisheries, aquatic habitat, and the natural environment base economy can be substantial. Climate change is expected to further add uncertainty to the frequency and magnitude of floods and droughts in the region and the realization of more extreme weather. The projected sea level rise due to climate change will have a negative consequence for the Mekong Delta by increasing the base flood level.

69. The implications of climate change have a number of consequences for flood and drought management in Cambodia. The consequences of climate change were derived considering the IPCC's Fifth Assessment Report and the investigations conducted under MRC's Flood Management and Mitigation Programme from 2010 to 2015. There is general consensus that Cambodia and the Mekong River basin will experience increased rainfall during the wet season through more intense rain storm events. Rainfall during the dry season is expected to remain unchanged or be slight lower. The estimate for the magnitude of change varieties under the various climate scenarios, however the direction of the change is consistent. Temperatures during the dry season are expected to increase, which will have significant consequences for the increased potential of prolonged droughts. The implications of climate change on flood levels and duration is further complicated by future upstream development of dams as well as landscape changes and developments on the floodplain.

70. The consequences of climate change and future developments in the floodplain for a 2060 design horizon are significant. The 2060 design horizon provides a design life of some 40 years for infrastructure currently in the planning stage. Sea level rise is expected to approach 0.5 m by 2060, which will increase water levels at Phnom Penh by some 0.2 m. Peak water levels at Phnom Penh for a 1:100 year event is expected to approach 0.3 m for a moderate climate change scenario and over 1.2 m for the extreme scenario. This increase in water level for even the moderate scenario is expected to lessen the existing flood protection works to less than a 1:20 year event. The duration of flooding is predicted to be extended by 14 days for a moderate scenario.

71. Approaches to lessen the negative affect of floods and droughts may consist of structural and non-structural measures. A number of studies for the region have raised caution with respect to the wide spread use of structural measures given the implications for loss of the natural floodplain function. The MRC Flood Management and Mitigation Programme 2011-2015 conducted a number of studies related to flood challenges and flood management strategies. The findings of these studies hold true today and provide the bases for recommendations on refinements to the Cambodia's flood and drought risk mitigation strategy. Adaptation is the core mitigation strategy that emerges combined with selected and cautious use of structural measures.

72. Adaptation is a process through which societies make themselves better able to cope with natural hazards and an uncertain future due to climate change. Adapting entails taking the right measures to reduce the negative effects, or exploiting the positive ones, of natural hazards and climate change by making the appropriate adjustments and changes. Adaptation options and opportunities range from technological options such as increased flood defences or flood-proofing houses, to flood and drought risk management through land use and zoning, to behaviour change such as reducing the use of water intense

crops in times of drought. Other adaptation strategies include early warning systems for extreme events, better water and land management, improved risk management, insurance options, and biodiversity conservation. Planning in an adaptive way is proposed as a strategic direction for flood and drought risk management in Cambodia. Previous studies have referred to this strategic direction as “living with floods”. The approach considers the use of structural protection works by flood proofing of settlements and transportation infrastructure and adaptations such as the use and/or development of less vulnerable rice varieties to inundation. Drought adaptation approaches suggest greater use of low intensity irrigation, use of drought tolerant crop varieties, and, greater use of water retention schemes and groundwater. Whether the adaptation approach is for floods or droughts, considerations must be given to maintaining sensitive and valuable ecosystems such as seasonally-inundated riparian forests; seasonal wetlands including marshes, small pools and pools; and seasonally inundated grasslands. These ecosystems are important as a habitat for a variety of fish and water birds and for the sustenance of the inland fisheries.

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