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Methods and Tools Applied for Climate Change Vulnerability and Adaptation Assessment in Cambodia's Tonle Sap Basin

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LIST OF ACRONYMS

ADM	Adaptation Decision Matrix
BCR	Building Community Resilience
BSM	Basin Simulation Model
CBA	Cost Benefit Analysis
CDRI	Cambodia Development Resource Institute
CEA	Cost Effectiveness Analysis
CREATE	Climate Resilience Evaluation for Adaptation through Empowerment
CVAC	Climate Vulnerability and Adaptive Capacity
CVCA	Climate Vulnerability and Capacity Analysis
CWSAFE	Climate Resilience and Water Security Assessment Framework
DHRW	Department of Hydrology and River Works
DRR	Disaster Risk Reduction
DSF	Decision Support Framework
DST	Decision Support Tool
GCM	General Circulation Model
GIS	Geographical Information System
HDI	Human Development Index
IIED	International Institute for Environment and Development
IPCC	Intergovernmental Panel on Climate Change
IQQM	Integrated Water Quantity and Quality Model
ISIS	Suite of flood risk, water flow, hydrology, water quality and sediment transport models
ITC	Institute of Technology of Cambodia
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resource Management
MCA	Multi-criteria Analysis
MOE	Ministry of Environment
MOWRAM	Ministry of Water Resources and Meteorology
M-POWER	Mekong Program on Water, Environment and Resilience
MRC	Mekong River Commission
PCVA	Participatory Capacity and Vulnerability Assessment
PRA	Participatory Rural Appraisal
PRECIS	Providing REgional Climates for Impacts Studies
PVA	Participatory Vulnerability and Adaptation
RUA	Royal University of Agriculture
SIMVA	Social Impact Monitoring and Vulnerability Assessment
SWAT	Soil and Water Assessment Tool
TSA	Tonle Sap Authority
TSB	Tonle Sap Basin
UNFCC	United Nations Framework Convention on Climate Change
URBS	Unified River Basin Simulation
V&A	Vulnerability & Adaptation
VCA	Vulnerability and Capacity Assessment
VRA	Vulnerability Reduction Assessment

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EXECUTIVE SUMMARY

Cambodia is highly susceptible to natural disasters due to the frequency and intensity of extreme climatic events, primarily floods, droughts and windstorms, but also in particular to increased climate variability.These disasters and climate-related hazardshave exacted huge socioeconomic costs on the country's economy and people's livelihoods, especially in the last decade. It isimportant, therefore, to understand not only the level of impactbut also the vulnerability and the capacity of people to adapt to these hazards. This emphasises the needfor vulnerability and adaptation assessmentsthat are tailored to site-specific local scale.

This paper reviews existing methods and tools used for understanding the impacts of climate change, the vulnerability and the adaptive capacity of local people, with a particular focus on water use and governance in three project target areas in the Tonle Sap Basin, under the project "Climate Change and Water Governance in Cambodia". The objectives of this review are twofold: to understand how different organisations have approached the evaluation of vulnerability and adaptive capacity in relation to climate change and water governance; and toanalyse the strengths and gaps in existing tools and methods based on how they address vulnerability and adaptation as a function of exposure, sensitivity and adaptive capacity.

The tools and methods that have been applied by various organisations in different institutional settings and at different geographical scales and locationscan be broadly grouped under three categories: climate, hydrologicaland socioeconomic modelling and downscaling; participatory approaches that engage local communities; and decision support tools to evaluate alternative adaptation strategies.

To detect trends and understand the implications of climate change at the local level, the regional climate modelling system Providing REgional Climates for Impacts Studies (PRECIS) can be used to downscale the outputs of general circulation models (GCMs) from the national scale (Cambodia) to catchment (Tonle Sap) scale.Hydrological models, the Soil and Water Assessment Tool (SWAT) and Integrated Water Quantity and Quality Model (IQQM) have been applied at the catchment level to generate new understandingabout river basin and human controls on the spatial and temporal distribution of water flow and to deepen understanding of supply-demand relationships. Also, ISIS—a software package that can simulate water flow, hydrology, water quality changes and sediment transport in rivers, floodplains, lakes, canals and coastal areas—has been used as a flood forecasting tool in the Tonle Sap Basin.

Participatory tools including climate vulnerability and capacity analysis (CVCA), community-based adaptation toolkits and participatory capacity and vulnerability assessment (PCVA) have been used to assess the impacts of climate variability and change on local livelihoods, especiallythose of vulnerable groups. This approach tries to understand how people directly experience the effects of climate change.

Cost benefit analysis (CBA) and multi-criteria analysis (MCA) are popularly used as decision support tools for selecting and prioritising interventions and/or projects as well as relevant policy areas relatedto climate change.

The review concludes that testing the extent of climate change vulnerability and adaptive capacity requires an integrated approach combining comprehensive vulnerability and adaptation assessment frameworks. Whether these vulnerability assessment frameworks should be applied simultaneously or one at a time dependson the specific context,data availabilityand resource requirements.

Indicators and indices that measure climate change exposure, sensitivity and adaptive capacity could be used to produce maps showing the spatial distribution of these three components of vulnerability. In the Tonle Sap, the indicators should be used for monitoring the extent of adaptation, mitigation and vulnerability at the community and local levels.

The selection, application and cost-effective use of appropriate databases,tools and methods, and the conduct ofcommunity and catchment-level vulnerability and adaptation assessments will eventually lead to recommendations for improved and locally-appropriate site- and context-specific vulnerability adaptation measures in the Tonle Sap Basin catchments.

1

INTRODUCTION

This report was prepared in respect of the project “Climate Change and Water Governance in Cambodia” (IDRC project 107088-001). This research aims to understand the interactions between changes in natural and human systems that affect water security in catchment areas, and what bearing these effects have on the vulnerability and adaptive capacity of the population in the areas affected.

The main activities of this study included developing an appropriate framework for assessing and monitoring vulnerability and adaptation (V&A), assessing data and information needs and gaps, and undertaking a desk-review of qualitative and quantitative methods and tools for V&A assessment for adaptation planning purposes. The study also provided recommendations on appropriate indicators to ensure methodological consistency for future studies and climate-informed decision-making and planning in Cambodia.

1.1. Background

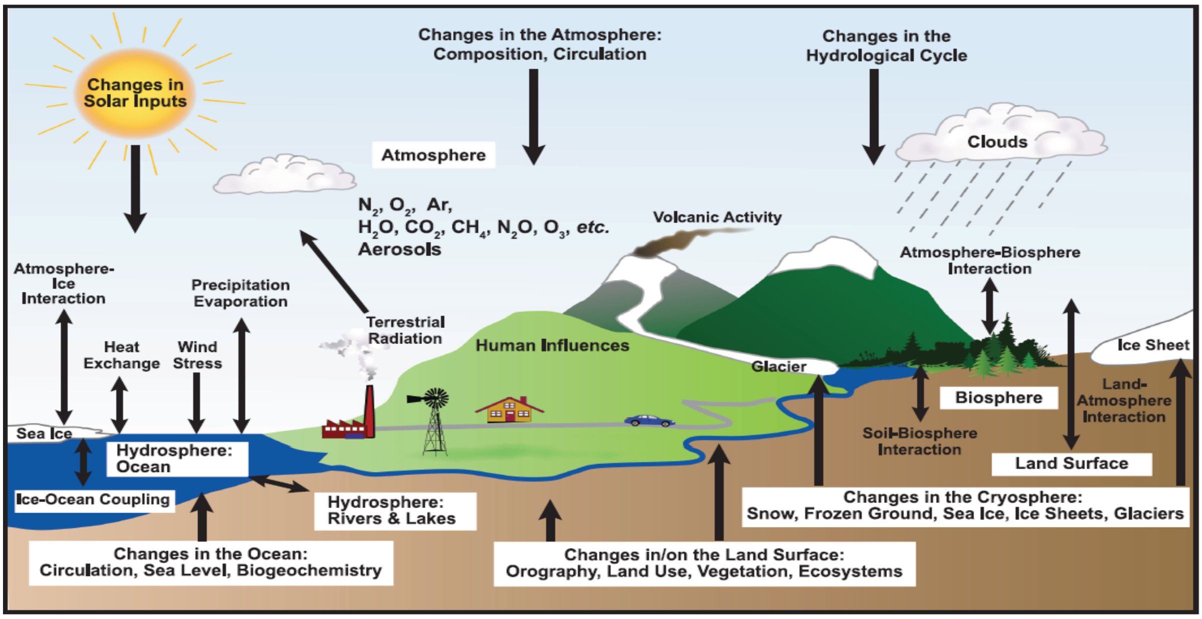
> Poor people, often dependent on natural resources for their livelihood, are the most affected by environmental degradation and natural disasters (fires, storms, earthquakes), whose effects are worsened by environmental mismanagement. (World Bank 2012: 14)

Cambodia is prone to flooding, drought and windstorms, the frequency and intensity of which appear to have increased since 1989 when statistics began to be regularly recorded. These disasters and climate-related hazards have exacted huge socioeconomic costs on the country’s economy and people’s livelihoods. The 2000 and 2011 floods were the worst in recent history, resulting in a high number of internally displaced people, hundreds of deaths, and other losses. Widespread flooding in 2011 especially damaged much of the rural and urban infrastructure developed in last ten years in the Tonle Sap and Mekong floodplains.

The 2009 Typhoon Ketsana damaged 630 km of roads, which cost about USD25.5 million to repair. In 2011, floodwaters inundated 718 km of national and provincial roads spread out over 186 sections, and affected more than 1.7 million people in 20 provinces (MPWT 2012: iv). In 2013, the major flood events (flash floods and river floods) resulted in severe damage and losses to the value of approximately USD750 million to USD1.0 billion (MOE et al. 2012a:1).

It is important to examine how climate change impacts are detected and projected at fine scales, and to fully grasp the fact that weather can be highly variable on a daily, weekly, or even yearly basis, and that climate, which is based on longer time scales, can be variable as well – in Cambodia in general and in our selected study areas in particular. This investigation and its findings are critical for developing appropriate cost-effective adaptation measures in Cambodia and in our study areas, the provinces of Pursat, Kompong Chhnang and Kompong Thom around the Tonle Sap Lake.

Figure 1: Components Making up Climate Change and Its Impacts



Source: IPCC (2007: 104)

To answer these questions, it is important to understand what constitutes normal climate variability versus actual climate change in Cambodia. Climate variability can be thought of as the way climatic variables (such as temperature and precipitation) depart from the average, in that they are either above or below the climatic mean. Climate change is generally defined as a trend in one or more climatic variables such as temperature that are characterised by a fairly smooth continuous increase or decrease of the average value during the period of record, for example, for 10, 20, 30, 50 to 100 years, and so on (Teacher Guide, www.ucar.edu/learn).

Climate change, popularly defined as a change in the climate that persists for decades or longer, arising from either natural causes or human activities that alter the composition of the atmosphere (i.e. greenhouse gas emissions), is not the same as changes in the weather which may be more localised, and more short-term (UNDP and MOE 2011: 14).

Cambodian official reports state: "Climate change is real, and by all accounts is already being felt in Cambodia" (UNDP and MOE 2011: xi). At the same time, Cambodia has suffered from numerous natural disasters (particularly floods, droughts and storms). This indicates a pressing need to address both climate change adaptation and disaster risk reduction.

Cambodia contributes little to global climate change, yet it stands to be disproportionately affected by the negative impacts (MRC 2010a). Almost all of its provinces are vulnerable due to the low adaptive capacity of the population and their high dependence on climate-sensitive livelihood options such as farming and fishing (Yusuf and Francisco 2009). The Tonle Sap Basin (TSB) is particularly vulnerable, as climate change will affect its unique flood pulse system[1] and water regime. This includes a decrease or increase in the duration and extent of floods (Eastham et al. 2008). This change would further affect water quality, fish species composition and aquatic biodiversity in the Lake system.

[1] Ecosystems that experience fluctuations between terrestrial and aquatic states… and the hydrology of such systems can be described as a 'flood pulse'" (Kummu et al. 2006 cited in Keskinen et al. 2013: 10); the Tonle Sap lake-floodplain ecosystem "is closely connected to – and dominated by – the Mekong River" (MRCS/WUP-FIN 2007 cited in Keskinen et al. 2013: 10).

It is also important to indicate that the alterations in the Basin's hydrology are compounded by on-going and planned economic activities within the TSB and Mekong River Basin. A recent CDRI study included a comprehensive assessment of human-induced hydrological dynamics at catchment level (Chem and Someth 2011). Chem and Someth highlight that such direct anthropogenic changes are increasingly resulting in water stress and socioeconomic tension; many farmers now face water excess in the wet season, longer dry spells in the wet season and severe water shortages in the dry season. Further, there have been increasing reports of conflict between upstream and downstream farmers over competition for water (Chea et al. 2011: 27).

Competition and conflict over water are intensified by lack of proper water allocation mechanisms and lack of proper irrigation and crop planning within the catchments. Farmers have expanded their dry season rice fields, thereby increasing field water demand. At the same time, farmer water user communities in upstream areas started to extract more water, reducing the water supply for downstream areas. Similar hydrological changes have been observed in the TSB by a recent study led by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and funded by AusAID – "Exploring Tonle Sap Futures" (Keskinen et al. 2011). The study confirmed that in the next 10–20 years, changes in water and related resources will be driven more by economic activities such as the development and operation of dam and water storage infrastructure, and that climate change and variability will further critically increase uncertainties related to natural water supply.

Future changes in climate and natural systems, under the projected climate in 2030 for the Lower Mekong Basin, encompassing Cambodia, are expected to include an increase in mean temperature of 0.79 ^{o}C, an increase in annual precipitation of about 0.2 m (13.5 percent), and a decrease in dry season rainfall (Eastham et al. 2008: iv). These changes will result in higher water levels earlier in the year and prolonged flooding. Extreme weather is likely to become more prominent, with wetter rainy seasons and drier dry seasons. Further, since there will be less rain in the dry season and longer dry spells in the wet season, increases in the frequency of floods and droughts are expected (Chem and Kim 2014).

This study is able to confirm its hypothesis that changes in the Tonle Sap flood pulse and water regime over the next 30 years are more likely to be caused by infrastructural development, especially hydropower and irrigation dams, and by climate variability. But climate change will further increase uncertainties that need to be properly mainstreamed into decision-making to ensure climate resilience.

Testing this hypothesis requires an integrated approach that combines a comprehensive V&A assessment framework, mathematical modelling, outputs from climate scenario downscaling and interpretation, risk screening and decision-support tools. Required also is the conduct of participatory vulnerability assessments and adaptation planning to provide solutions for adapting infrastructure to anticipated climate-related impacts on water security at defined scales in the TSB.

1.2. Objectives, Rationale and Research Questions

The key objective of Mini Study 1 is to critically review existing methods and tools for conducting community and catchment-level V&A assessments[2] in order to support appropriate

2 Vulnerability and adaptation (V&A) assessment is a process of defining vulnerability to, or risk from, changes in climate, other environmental variables and social conditions at several scales and levels (MOE et al. 2012c: 2).

recommendations for improved site- and context-specific vulnerability adaptation measures in the TSB catchments. The identified methods and tools will be considered for further development and application by Mini Study 2: Participatory V&A Assessment, and Mini Study 3: Water and Climate Change Governance.

There are some studies describing V&A assessments in Cambodia (see, for example, Yusuf and Francisco 2009; RGC 2006; UNDP and MOE 2011). However, there are observed differences in the ranking and results of the V&A assessments among these studies due to the different data quality and assessment methods, as well as the various scales of quantitative and qualitative approaches. These studies fall short in incorporating changes due to direct human activities. As a result, there is a need to review different research methods and to validate the findings (Yusuf and Francisco 2009; RGC 2006; UNDP and MOE 2011).

Mini Study 1 reviewed the methods used and outcomes of existing V&A assessments, and recommended appropriate methods for conducting and applying V&A assessments in the selected project sites to address specificities at commune and village level. This validation is needed to examine different methodologies for measuring vulnerability and adaptive capacities. Furthermore, the outcomes of the study provide preliminary information and set the direction for the rest of the project. They also inform national and subnational multi-stakeholder consultations, capacity building and awareness raising events involving institutions and individuals over the course of the project. More specifically, the study presents the following opportunities:

1. to conduct V&A assessments at catchment and community level to recommend locally appropriate adaptation planning for the TSB catchments (Kompong Chhnang, Pursat and Kompong Thom);
2. to assess the impacts of natural and anthropogenic changes on water security at finer scales – communes within catchments and sub-catchments;
3. to understand existing governance and to identify capacity needs and gaps for water resources management and adaptation planning in light of anticipated anthropogenic and climatic changes;
4. to assess and select the most appropriate climate scenario downscaling tools and information, and decision support tools, to facilitate water resource management and climate change adaptation decision-making in the selected sites in the TSB.

Given these overall objectives and rationale, the research questions for this study can be stated as follows:

Q-1 What are the different methods and tools for conducting V&A assessments at community level?

Q-2 What indicators can be used to monitor different components of vulnerability (exposure, sensitivity, adaptive capacity)?

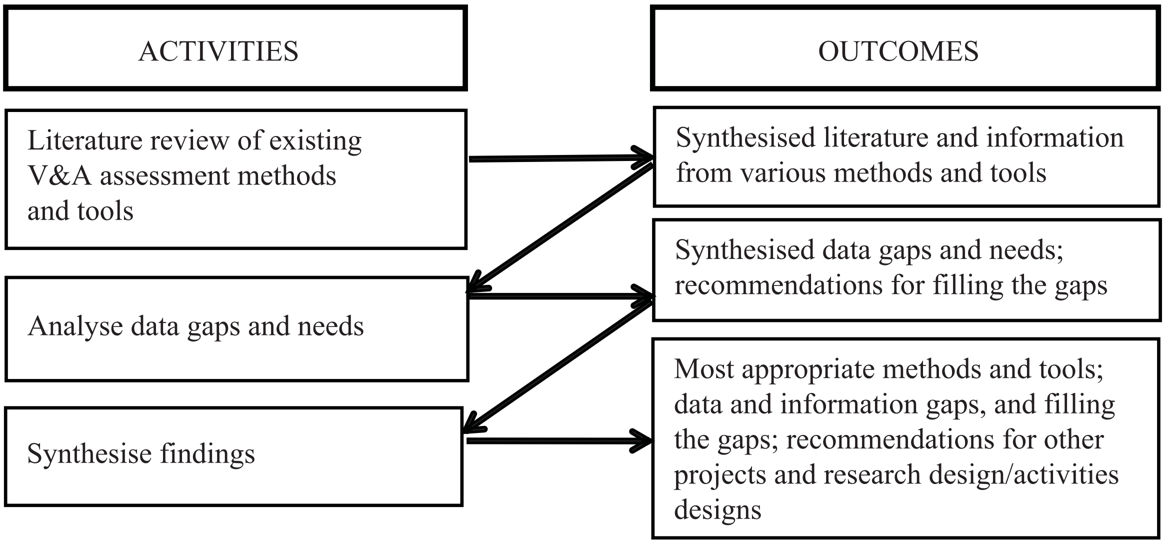
Q-3 How can existing methods and tools be harmonised to improve the robustness and validity of vulnerability studies and address the site- and context-specific nature of V&A?

2

METHODOLOGICAL FRAMEWORK

Figure 2 summarises the step-by-step approach forming the framework of Mini Study 1 and the expected outcomes. The key steps are 1) desk review of existing vulnerability and adaptation (V&A) assessment methods and tools; 2) analysis of data gaps and needs; and 3) synthesis of the findings and recommendations for further studies and application of research results.

Figure 2: Planned Activities and Expected Outputs of the Study



2.1. Literature Review

To respond to the research questions in Section 1.2, the Mini Study 1 team undertook a desk study of academic and non-academic reports and publications from the country, the Greater Mekong Subregion (GMS) and other countries around the world, including:

1. Review of Community Based Vulnerability Assessment Methods and Tools (Ministry of Environment, Government of Nepal 2010);
2. Review of Climate Change Adaptation Methods and Tools (MRC 2010b);
3. Impacts of Climate Change and Development on Mekong Flow Regimes: First Assessment (MRC 2010c);
4. Listen to Villagers on Climate Change: Vulnerability Reduction Assessment (VRA) (UNDP 2010);
5. Social Impact Monitoring and Vulnerability Assessment (SIMVA) (MRC 2010d);
6. Building Resilience: The Future of Rural Livelihoods in the Face of Climate Change, Cambodia Human Development Report 2011 (UNDP and MOE 2011);

7. Compendium on Methods and Tools to Evaluate Impacts of, and Vulnerability and Adaptation to, Climate Change (UNFCCC 2013);
8. Modelling tools to analyse climate change impacts and to develop and assess adaptation options, particularly the Decision Support Framework (DSF) for water quantity modelling and the environmental impact assessment (EIA) tools for Integrated Water Resources Management (IWRM), water productivity and water quality;
9. Comprehensive monitoring and modelling project reports, which provide analyses of the functioning of the Tonle Sap system, its productivity and the impacts of upstream developments (Sarkkula and Koponen 2010);
10. Community-Based Adaptation Toolkit (CARE 2010);
11. Participatory Capacities and Vulnerabilities Assessment (PCVA): Finding the Link Between Disasters and Development (Oxfam Great Britain 2002);
12. Climate Vulnerability and Capacity Analysis (CVCA) Handbook (CARE 2009).

The main outputs from this literature review include a research working paper, a technical brief, and presentation and awareness-raising materials used at the outreach workshops for subnational department and community representatives in Kompong Thom, Pursat and Kompong Chhnang, and at provincial and national workshops. They cover: (i) gap analysis of national knowledge and understanding of the impacts of climate change on water resources, (ii) appropriateness and applicability of V&A assessment methods and tools in Cambodia, and (iii) recommendations on methods and tools for conducting V&A assessments in the target catchments in Kompong Chhnang, Pursat and Kompong Thom provinces.

The desk review and subsequent consultation with key stakeholders concluded that it is important to define and share common understanding of some key terms such as water security, V&A assessment, climate change adaptation, and so on.

Box 1: Definitions of Water Security

Cook and Bakker (2012: 96) define water security as access and affordability of water for human needs and ecological health and sustainability. This brings together three schools of thought:

1. Water availability. Research on water security often focuses on water availability, assessing water quantity and measuring water stress and water shortage. The measurement of water stress (demand driven) evaluates the ratio of water use to availability, i.e., how much water is withdrawn. The water shortage measurement (population driven) is based on the percentage of the population sharing the water. This perspective emphasises water security as a sufficiency of safe water supply for human daily needs: drinking, hygiene, washing and livelihoods.
2. Water security and hazards (flood and drought) and infrastructure development. This perspective emphasises safeguarding access to water functions and services, and evaluates water security in relation to prevention of and protection from contamination.
3. Water security and sustainability. This view combines these two perspectives and assesses water security at all levels, from household to global needs: every person should have access to adequate safe water at an affordable cost while ensuring that the natural environment is protected and enhanced (GWP 2000: 12).

Water security is a main paradigm. The study investigates how changes in water resources development/management and climate will affect water security, the main component for achieving food security and rice commercialisation (according to Rectangular Strategy Phase III 2014-18), and how changes in water security will further exacerbate vulnerability and adaptation, and how to respond to that.

According to the Global Water Partnership's Global Strategy for 2009-13, a "water secure world integrates a concern for the intrinsic value of water with a concern for its use for human survival and well-being" (www.gwp.org/). Water security is framed as an issue of accessibility and affordability of a certain quality and quantity of water at selected sites and points of time for human needs and for ecological health (GWP 2009cited in Cook and Bakker 2012: 97).

In this study, "water security" is defined as the ability and capacity to harness the productive power of water and to minimise its negative impacts. Hence:

1. every person has enough safe, affordable water to lead a clean, healthy and productive life;
2. communities are protected from floods, droughts, landslides, erosion and water-borne diseases; and
3. environmental management is properly addressed and the negative effects resulting from poor management and governance are minimised.

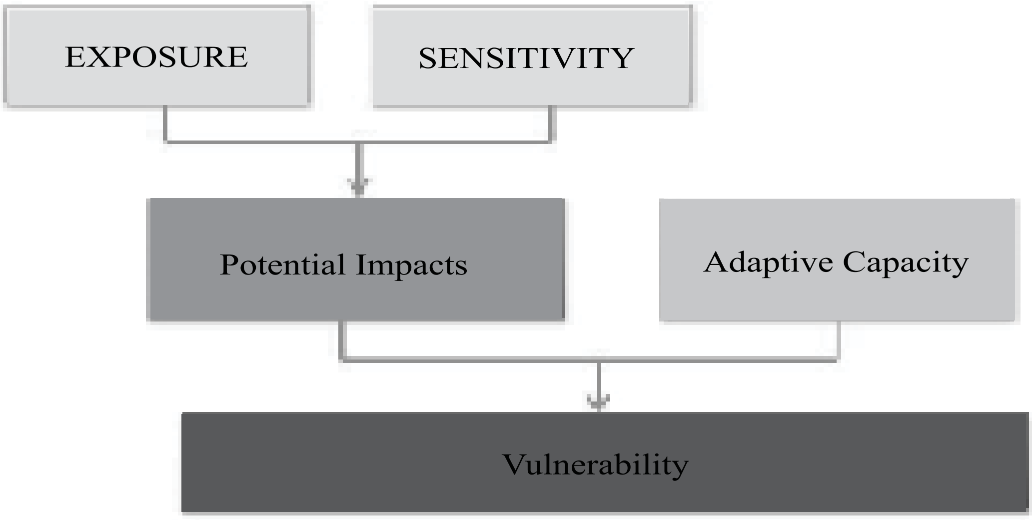
The term "vulnerability" is used in many different ways by scholars from various research communities, and disagreement about the appropriate definition is a frequent cause of misunderstanding in interdisciplinary research on climate change. This disagreement is also "a challenge for attempts to develop formal models of vulnerability" (Füssel 2007: 155). The Intergovernmental Panel for Climate Change (IPCC 2001a: 982-996) defines the vulnerability of a system as a function of the inter-relationship between three concepts: exposure, sensitivity and adaptive capacity.

> *Exposure* is "the nature and degree to which a system is exposed to significant climatic variations."
>
> *Sensitivity* is "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli."
>
> *Adaptive capacity* is "the ability of a system to adjust to climate change (including climate variability and extremes), to moderate the potential damage from it, to take advantage of its opportunities, or to cope with its consequences."

The relationship between exposure, sensitivity, adaptive capacity and overall vulnerability is depicted in Figure 3.

Climate change adaptation needs and the prioritisation of adaptation options and technologies will flow from the results of site-specific vulnerability assessments to be conducted under the mini studies. It is expected that the adaptation needs and priorities identified will reflect local climate risks and system vulnerabilities, and their impacts on water security, as well as changes in system sensitivities and adaptive capacities, as analysed in the site-specific vulnerability assessment.

Figure 3: Conceptual Relationship between the Different Components of Vulnerability



Source: MRC (2010b: 5)

Box 2: Definitions of Key Terms Used in V&A Assessment

***Vulnerability Assessment*:** Vulnerability assessments examine the underlying socioeconomic and institutional factors, and, to a lesser extent, political and cultural factors that determine how people respond to and cope with climate hazards (Adger et al. 2004: 6). These assessments are a useful tool with which to assess people's needs for adaptation. Vulnerability assessments do not require detailed climate information generated by models and they do not require us to wait until the science of climate prediction is more developed (Adger et al. 2004: 6.).

Vulnerability assessments aim at identifying selected determinants, sometimes to quantify them for comparative purposes, and they may also be performed to study the capacity of a system to cope or adapt to a stress (MRC 2010b: 8). Downing and Patwardhan (2004 cited in MRC 2010b: 8) list the following outputs of vulnerability assessments:

- A description and analysis of present vulnerability, including representative vulnerable groups (for instance specific livelihoods at risk of climatic hazards)
- Descriptions of potential vulnerabilities, including an analysis of pathways that relate the present to the future
- Comparison of vulnerability under different socioeconomic statuses, climatic changes and adaptive responses.

***Adaptation Assessment*:** Adaptation assessment is the process of identifying options to adapt to climate change and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency and feasibility (IPCC 2001a: 982).

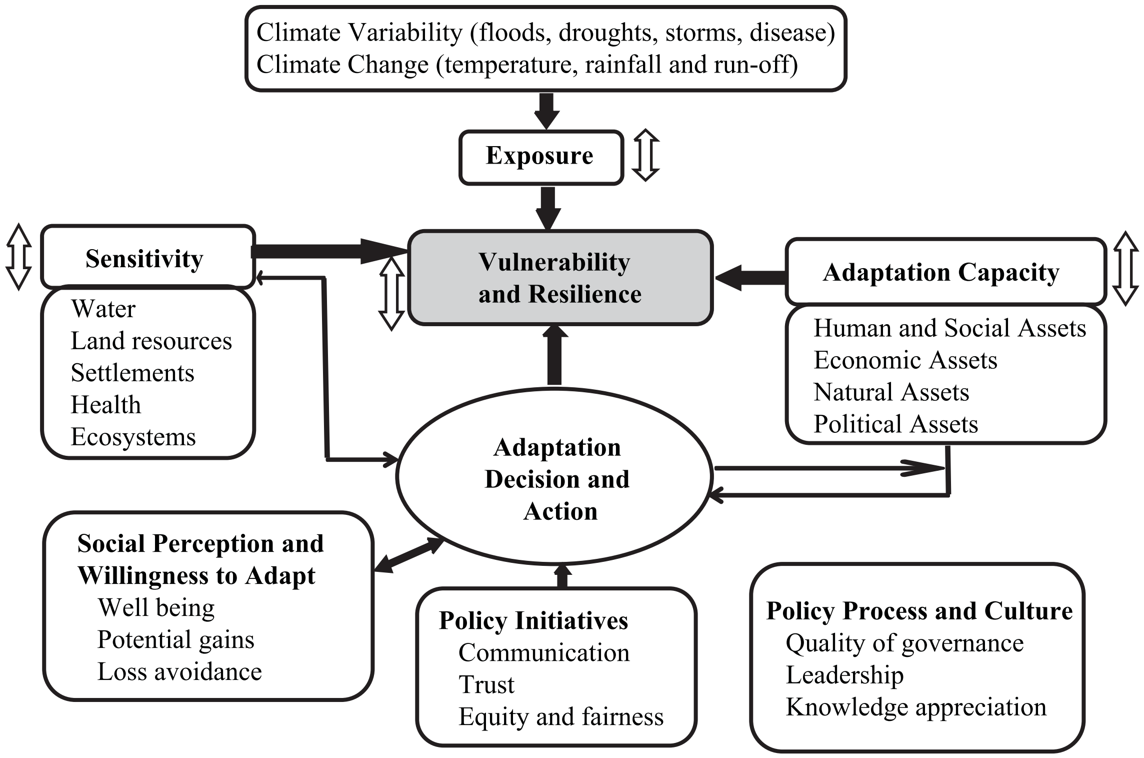
***Scenario Development*:** A scenario is a plausible and often simplified description of how the future might develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships (IPCC 2001a: 993). Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a "narrative storyline".

Climate change adaptation refers to the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2007: 6). Generally, in Cambodia, the need for improved adaptation to climate variability and change and the need for water security and human development often strongly overlap. As pinpointed in the definition from IPCCC, adaptation is a selective response strategy. Given that climate change can have both harmful and beneficial impacts on a system, adaptation seeks to capitalise on the opportunities and address the challenges presented. Various categories of adaptation are identified in the literature (IPCC 2001a).

2.2. Climate Resilience and Water Security Assessment Framework (CWSAFE)

Climate-related vulnerabilities are assessed in depth by this project for selected communities in the three provinces of Kompong Thom, Pursat and Kompong Chhnang. For this purpose the study proposes the Climate Resilience and Water Security Assessment Framework (CWSAFE), which is based on the Vulnerability-Resilience Indicators Model (VRIM) (Ibarrarán et al. 2008).

Figure 4: Schematic Diagram of Change Concept for Water Security and Climate Change



Note: When sensitivity is high (↑) resilience will be low (↓); if capacity to respond is high (↑) resilience will be high (↑). This sign (↑) implies an assumption of increasing and this sign (↓) implies an assumption of decreasing. If specific exposure events, such as a drought or flood, occur, resilience will decrease (either an interruption in an increasing variable or a further dip in a decreasing variable).

Source: Adapted from Ibarrarán et al. (2008: 06)

The main purpose of CWSAFE is to benchmark and monitor the ability of communities and catchments to adapt to, to cope with, and recover (resilience) from, changes and shocks induced by climate variability and change. This includes human activities (dams, water diversions and so on). It focuses on basic human needs, human and social assets (human resource quality and institutions, access and governance), natural assets, and financial/economic assets in relation to changes in critical trends, shocks and seasonality (Esty et al. 2005). The factors are important because they have a direct impact on asset status (sensitivity and capacity). Shocks such as floods, droughts, storms, civil conflict, and economic crises can directly destroy social, human and natural assets.

The magnitude, frequency and probability of these events must be recorded and projected/forecasted based on the high quality data that is available. This approach represents a positive evolution in thinking around vulnerability and water security, today and in the future, as the priority concern and focus for development. It is important that relevant variables are chosen through extensive literature review, assessment of data gaps and needs, rigorous analysis, and broad-based consultation with decision-makers, researchers and members of communities of practice, and indicator experts (European Environment Agency 2006: 35).

To understand the degree to which people are sensitive to climate impacts, and their capacity to cope and adapt, it is important to have a full grasp of a range of socioeconomic, institutional and political factors. Such factors include assets and resources (natural, economic, social), accessibility to these (wealth, and poverty, power and influence), where people reside and from where they draw their resources, as well as how climate risks and effects of economic activities are interpreted and perceived (IPCC 2001a).

The "access" perspective embraces the access each household and individual has to resources, institutions and processes in order to achieve climate change resilience and water security (Nicol 2000). The institutions that support this access and the processes used have a profound influence.

3

DATA GAPS AND NEEDS ASSESSMENT FOR SITE AND CONTEXT SPECIFIC V&A ASSESSMENT

Site- and context-specific vulnerability and adaptation (V&A) assessments are critical in anchoring current knowledge about climate change impacts to present and future development planning. As vulnerability is a relative measure, vulnerability indicators and mapping processes can be selected based on choices by the team, stakeholders and the vulnerable groups themselves. To develop and use indicators for monitoring V&A, the project needs to be aware of several technical issues, such as their sensitivity to change, techniques for standardisation of indicators, data quality, alignment between indicators, coverage of relevant dimensions of vulnerability, and so on (Downing et al. 2004: 73). These issues dictate the quantity and quality of the data and the consequent ability to derive a sound assessment of V&A.

Mini Study 1 used a structured approach to the data needs and gap analysis for the V&A assessment from the current climate variability and long-term climate change predictions, as well from other external and local economic activities such as reservoir regulations and local land use practices.

Data and information are needed to understand the boundary and baseline conditions of the selected key assets and their subsets, and to monitor changes over time. The data for V&A assessments provides the baseline for monitoring the following aspects of vulnerability:

- Exposure to current climate hazards (floods and droughts), including the frequency and intensity of those hazards and the damage caused by their impacts;
- Factors that contribute to vulnerability (sensitivity and adaptive capacity);
- Vulnerability of water security to current climate hazards: how agriculture and water resources are affected by climate variability and hazards and other major economic activities;
- Factors that might contribute to long-term vulnerability: how future climate variability might trigger socioeconomic and environmental changes that affect sensitivities and adaptive capacities to climate risks.

This data should be collected and verified using participatory mapping at the selected study sites. The evaluation of site-level vulnerabilities will be informed by both existing data and information gleaned through data collection, literature search and consultations with government officials, experts and community leaders and members. Some data and information already exist of different scales and of different degrees of quality, and these need to be collated and evaluated.

Data types might include those describing "exposure to hazards, sensitivity and adaptive capacity". For exposure, we need to know the population distribution and spatio-temporal variation; livelihood activities; ecosystem services and resources; access to infrastructure and facilities; and economic, social and cultural assets that could affect vulnerability and livelihoods

(IPCC 2012: 3). Data helps us to construct a development baseline and target vulnerable groups – who they are, where they are, and what makes them particularly vulnerable.

In addition to information on the socioeconomic aspects and governance, data on the following is also important: agricultural productivity; water/food availability and demand (temporal and spatial); temperature and annual precipitation (10-30 year time series); annual runoff; dry season water stress; flooding and drought frequency and magnitude; seasonal variation of the Tonle Sap's water level and volume, flooded forest areas, land use, fish habitats and fisheries; water-related infrastructure, irrigation, reservoir operation, housing and road infrastructure.

Accurate and comprehensive hydrometeorological information allows better understanding and produces reliable assessments (MOE et al. 2013). This includes:

- Hydrometeorological processes and quantities that affect various water uses as most rural livelihoods in Cambodia depend on water resources, as do secondary production and services
- Crop water requirements, farm water losses and evaporation, surface and ground water availability, and climate variability and risks
- Baseline information and predicted or projected changes.

Resolution measured over time may range from annual, seasonal and monthly averages to daily or sub-daily time steps. Moreover, the most common variables applied in impact studies are observations of air temperature and precipitation, solar radiation, humidity, wind speed, accumulated temperature, evapotranspiration and runoff (computed directly from primary observations). In some cases, long-term averages and annual time series are essential.

The measurement of assets can be derived from a variety of resources (observed data and key statistics), indicators and indices, collated and developed through intensive data collection, surveys and questionnaires carried out by multilateral organisations and non-government organisations (see Appendix 3).

Data is obtained from different sources, having been collected based on pre-determined standards and methodologies. Therefore, data handling requires great care, appropriate analysis methods and a standardised approach. This ensures that it is properly representative and can be used realistically in comparisons.

The meteorological and hydrological data generated by existing networks in all three selected sites have the following shortcomings: (i) raw data is collected with limited preliminary screening and quality control; and (ii) in some circumstances, data processing procedures are not strictly followed. Furthermore, data sharing between ministries is limited (MOE et al. 2013).

CDRI and ITC have collected hydrometeorological data from a few locations in Kompong Chhnang. The data coverage issues need to be discussed with partners from MOWRAM, TSA, and MOE to determine effective methods for identifying and filling gaps. For example if the rainfall station at Pursat (ID: 120302) can be used as a representative station for the Stung[3] in the Pursat catchment, then daily data and records are available for a period of 29 years (1981-2011).

[3] The Khmer word *stung* means "stream".

Groundwater is widely used for domestic water supply throughout the country and, through the development of tube-wells, is increasingly drawn on for supplementary irrigation in some provinces. However, there is no formal national groundwater monitoring at an institutional level due to confusion about different departments' roles and responsibilities. A number of line ministries are dealing with groundwater.

There are a number of alternative sources of baseline climate data such as from the Department of Meteorology (DOM) of MOWRAM, regional and global datasets, and climate model outputs that can be applied in impact assessments. For Cambodia, such datasets include the Global Runoff Data Centre run by the German Meteorological Service (www.bafg.de), and daily discharge data for the Mekong River and tributaries for Cambodia (17 stations), Laos (four stations), Thailand (seven stations) and Vietnam (one station); most data starts from around 1960 and continues to the 1990s but some stations also have more recent data.

4

REVIEW AND SELECTION OF EXISTING V&A ASSESSMENT METHODS AND TOOLS

In terms of methods and tools for vulnerability and adaptation (V&A) assessment, various guidelines, models, toolkits and frameworks have been created. These range from complex models to assess climate change impacts to guidelines of the steps to take, from identifying, designing, implementing and evaluating vulnerability to planning adaptation measures (MRC 2010b: vii).

Box 3: Definitions of Approach, Methods and Tools

***Approach*: "**A complete framework that prescribes an entire process for the assessment of vulnerability and adaptation and offers a broad strategic approach. An approach in some instances assembles certain methods and toolkits to support this process" (UNFCCC 2008: 1-12). The UNDP Adaptation Policy Framework (2004) provides an overview of how adaptation should be approached, rather than a specific set of 'instructions' (MRC 2010b:3).

***Method*: "**A set and sequence of steps that should be followed in order to accomplish a specific task within a larger framework. A method can be implemented through using a number of tools" (UNFCCC 2008: 1-12). Vulnerability and capacity assessment is a method for which a number of tools can be used (MRC 2010b:3).

***Tool*: "**A means or instrument though which a specific task is accomplished" (UNFCCC 2008: 1-12). It includes impact models, decision tools (cost benefit analysis), and stakeholder tools (vulnerability indexes) (MRC 2010b:3).

4.1. V&A Methods and Tools

United Nations Framework Convention on Climate Change (UNFCCC 2013) lists 127 different methods and tools grouped into three main categories: sector (e.g., agriculture, forestry), theme (e.g., climate scenarios, impact assessment) and type (e.g., guidance documents, modelling tools). Entries are searchable through these three "filters".

Climate change decision-making, and the decision analysis intended to support it, can be structured in three major domains: decision-making *per se* (the act of formulating decisions), decision analysis (aimed at providing information for decision-makers), and process analysis (investigating procedures of decision-making) (IPCC 2001b: 606)

Table 1: Methods and Tools Categorised by Sector, Theme and Type

Sector	Theme	Type
Agriculture (31) Coastal resources (11) Generic (56) Human health (7) Multiple (4) Terrestrial ecosystems (10) Water resources (13)	Adaptation evaluation (43) Adaptation planning (18) Climate scenarios (28) Economic analysis (15) Impact assessment (51) Mainstreaming (2) Methodological framework (25) Sea level scenario (11) Socioeconomic scenario (13) Stakeholder engagement (26) Vulnerability mapping (12)	Guidance document (27) Knowledge platform (4) Modelling tool (60) Resources (case studies) (4) Resources (data) (5) Risk screening and adaptation Decision support tool (48)

Note: For example, of the 127 identified tools, 31 are categorised under agriculture, 43 under the adaptation evaluation theme, and 27 as types of guidance documents.
Source: UNFCCC (2013)

Cambodia's experience with decision support tools (DSTs) was gathered mainly through the Mekong River Commission (MRC) and through preparation of its national communications to the UNFCCC. Under the National Communications Framework, climate change impact assessments were conducted for key sectors using a variety of climate modelling tools and emissions scenarios. MOE et al. (2012b: 1) carried out an evaluation of 126 different tools and frameworks from UNFCCC (2012), ranging from complex models developed to assess current and future climate risks, impacts, vulnerabilities and adaptation needs, to guidelines for identifying, designing, prioritising and evaluating adaptation measures. From the list of 126 different tools, 21 potential DSTs were found.

To help determine the impacts of both natural and human system changes towards assessing the level of V&A in the three selected catchments (Stung Chrey Bak of Kompong Chhnang, Stung Chinit of Kompong Thom, and Stung Pursat in Pursat) around the Tonle Sap Lake, four different types of methods and tools were suggested: climate change impact models, hydrological impact models, decision support tools, and stakeholder tools. Given the broad spectrum of adaptation responses that may be required for Cambodia to address current and future climate impacts, it is sensible to consider a wider range of tools designed for screening climate risks, for assessing current and future climate-related risks, impacts and vulnerabilities, and for identifying adaptation options. Moreover, in determining priorities, adaptation measures implemented at the subnational and/or local level require participatory evaluation approaches, with the involvement of key stakeholders such as community members, vulnerable groups or local decision-makers.

4.2. Modelling Tools

Models for hydrological, hydrodynamic and water quality assessment are very important. They can be used to plan the provision of quantitative inputs for V&A assessments and infrastructure resilience planning (houses, storage facilities, flood protection structures and road embankments). However, greater learning requirements impose a need for more versatile and powerful tools. For the appropriate choice of a model, the following aspects are important (MK16 Project Team 2013: 6):

- The physical processes including river or flash floods, and backwaters. For instance, hydrological routing models should not be used for areas under flow reversal regimes, such as those of the Tonle Sap;
- The availability and quality of data. It is well known within the community of practice that regardless of the robustness of the mathematical model, the model's results are often compromised by poor quality data – "garbage in = garbage out". In Cambodia the outputs of many flood models are affected by the lack of and poor quality topographical data. That said, a thorough analysis of available data might reduce garbage content to a certain extent; and
- Ability of the model to generate results with a good degree of certainty under extrapolated conditions. Experience shows that some flood models are unable to do so, even when good sets of data are available to calibrate them. Generally, the analyst is interested in a range of events that rarely occur, and for which observations are usually not available.

Table 2 presents the key tools applied to date by various organisations including MOE and MOWRAM and academic and research institutes in different catchment and subcatchment areas in the country.

Table 2: Typology of V&A Assessment Methods and Tools Applied in Cambodia and the Mekong Region

Method/Tool	Explanation	Method/Tool name
Impact models: climate change	Climate downscaling	PRECIS dynamic climate downscaling model
Impact models: hydrological change	Hydrological modelling	IWRM (Integrated Water Resource Management) model (MRC/World Bank) , SWAT (Soil and Water Assessment Tool) IQQM (Integrated Water Quantity and Quality Model) basin simulation model ISIS[a], an industry standard suite of modular software solutions developed for simulation of water flow, hydrology, water quality changes, and sediment transport in rivers, floodplains, canals and coastal areas Tank model[b], eWater[c]
Stakeholder tools	Local participatory assessment	Vulnerability indices, Community-based Adaptation to Climate Change (IIED) Climate Vulnerability and Capacity Analysis (CVCA) (CARE International) Framework for Social Adaptation to Climate Change (IUCN)
Other decision support tools	Decision-making	Multi-criteria Analysis (MCA), Cost Benefit Analysis (CBA), Cost Effectiveness Analysis (CEA)

IIED=International Institute for Environment and Development, IUCN=International Union for Conservation of Nature
Note: [a] www.isisuser.com/isis/ (accessed 5 May 2014); [b]Sugawara (1995); [c]Black et al. (2011)

A series of hydrological models have been applied in different riverine catchments in the country. For use in the Tonle Sap catchments, the study team proposed a combination of the Integrated Water Resource Management (IWRM) model; Soil and Water Assessment Tool (SWAT); Basin Simulation Model or Integrated Water Quantity and Quality Model (IQQM); ISIS – an industry standard suite of modular software solutions developed for simulation of water flow, hydrology, water quality changes, and sediment transport in rivers, floodplains, canals and coastal areas (www.isisuser.com/isis); and the tank model (Sugawara 1995).

(Appendix 1 gives a detailed description and justification of these selected modelling tools.)

Providing REgional Climates for Impacts Studies (PRECIS), a regional climate modelling system, has been applied as the climate change impact model in the Mekong region and in Cambodia. Some key members of the project team have a good understanding of and experience in using this model. Because the PRECIS model has already been run at regional level, there is no benefit in repeating this wide-scale exercise. Instead, it is necessary to downscale the model or to use the existing results from PRECIS as they relate specifically to the project sites in Kompong Chhnang, Pursat and Kompong Thom; therefore, downscaling of climate data (temperature and precipitation) uses the resolution of 0.2 x 0.2 degrees (equivalent to about 22 x 22 km of land area).

The following model types can be selected for water balance computation:

Rainfall-runoff models can be used to provide discharge information. They transform rainfall data into statistical information on water flow or river discharges. (MK16 Project Team 2013: 6). In the development of the Decision Support Framework (DSF) for the Lower Mekong Basin, the MRC Secretariat processed rainfall data for the period 1985-2000 to calibrate the SWAT rainfall-runoff models under the DSF. A better alternative could be to use newly developed Unified River Basin Simulation (URBS) models, calibrated under Flood Management and Mitigation Programme C1 (FMMP-C1) particularly for flood conditions. In principle, the URBS models would be able to show better calibration results than the SWAT models. However, this hypothesis has to be checked upon the selection of the models to be used for the study (MK16 Project Team 2013: 7).

Hydrological routing models are for identifying impacts of water resources development, including irrigation systems and hydropower dams on the flow regime and water availability of the river basin. The Simplified EXCEL Spreadsheet could be used due its simplicity and ease of use by team members (MK16 Project Team 2013: 7).

Soil and Water Assessment Tool (SWAT) can be run to identify the suitable adjustment methods by comparing outputs from model runs with adjusted Regional Climate Model data and with observed climate data for 1985-2000 (Mainuddin et al. 2010)[4].

Basin Simulation Model (BSM) can simulate water resources management scenarios to assess their effects on water balance within a geographical area and for water use in different sectors (MRC 2004). Its scope includes the whole river basin, representing key components of the water balance: inflows, return flows, storage decisions, storage operations, and consumption and non-consumption demands. It also has the general capability to simulate pollutants.

[4] The Commonwealth Scientific and Industrial Research Organisation (CSIRO) initiated the National Research Flagships to address Australia's major research challenges and opportunities.

4.3. Participatory Methods and Tools

The review was conducted of existing participatory methods and tools developed and used by different organisations for V&A assessment. The methodological aspects were analysed by comparison with a set of best practice criteria, presented in Table 3. The overall review, analysis and comparison were based on IPPC's definition of vulnerability and its three components: exposure, sensitivity and adaptive capacity. This identified guidelines to assess community vulnerability as well as quantitative indicators and qualitative data for downscaling the impact analysis.

Table 3: Best Practice Criteria

Issues categories	Criteria
Participatory methods and tools for V&A assessment	- What is the function of the participatory V&A method/ tool? Or what does the method/tool aim to achieve? - How is it used for assessing vulnerability in terms of how a system is exposed to change, its sensitivity to impacts and its ability to adapt to the impacts of hazards caused by climate change? - Is there evidence of application? - Is it simple to use or does it require training and other inputs?
Indicators	- What reliable quantitative and qualitative indicators are there for downscaling climate change impacts?
Identifying and evaluating adaptation options	- Does it promote integration with development planning and management? - Does it consider relevant social, environmental, economic and institutional issues and impact analysis? - Does it consider issues related to gender and minority groups?
Institutional and empowerment issues	- Is it transparent? - Does it also involve stakeholder participation? - Is it politically feasible for application in Cambodia? - Is it gender responsive?

The review revealed that the participatory V&A assessment is commonly used by different organisations to empower community members to systematically analyse their problems, suggest their own context-specific solutions and identify the means to achieve those solutions (UKaid 2011; McNamara and Limalevu 2011). The PVA assessment is also a bottom-up approach for identifying appropriate solutions to reduce hazards or risks caused by climate change. Used as an entry point for community-based action, it places community knowledge, experiences and attitude towards climate change at the centre of V&A capacity assessments and in designing locally-specific adaptation strategies.

The participatory rural appraisal techniques and tools such as focus group discussions, key informant interviews, and sharing and learning dialogues will be used and triangulated with secondary data, and regional and national scientific V&A analyses. These activities will be used for designing specific interventions involving community structures and processes:

1. to document the communities' understanding of climate change and its impact on their livelihoods
2. to identify the key vulnerabilities of the target communities
3. to document how communities perceive risks and threats to their lives and livelihoods

4. to help communities analyse their resources (capacities) and the strategies available in their communities that can be used to mitigate the identified risks or hazards
5. to help the communities to develop their own action plans
6. to establish baseline data for programme evaluation.

Local evidence and perceptions of vulnerability will be collected, analysed and triangulated with secondary data for programme planning across a range of adaptation measures for risk/hazard reduction, food security, poverty reduction and sustainable livelihoods. The practical guidelines for data collection and analysis using participatory V&A assessment tools are documented in Appendix 2.

Box 4: Brief Description of Selected Tools for PVA Assessment

- *Department of International Development (DFID), UK,* Sustainable Livelihood Guidance Sheets provide tools (including tools to guide environmental assessment), a checklist, gender analysis guidelines, governance assessment, institutional appraisal, macroeconomic analysis, participatory poverty assessment, stakeholder analysis, strategic conflict assessment, and rapid and participatory methods for assessing livelihood vulnerability.
- *CARE* Climate Vulnerability and Adaptive Capacity (CVAC) and Community-Based Adaptation toolkits based on a sustainable livelihoods approach suggest the following tools for data collection and analysis: hazard mapping, seasonal calendars, historical timelines, vulnerability matrices and Venn diagrams.
- *Stockholm Environment Institute (SEI)* Adaptation Toolkit is a comprehensive set of practical tools for conducting climate change vulnerability assessment and for developing a strategic adaptation plan based on current capacities.
- *International Union for Conservation of Nature (IUCN)* guidance list includes 16 indicators for assessing household-scale adaptive capacity and 8 indicators for community/industry-scale adaptive capacity.
- *International Institute for Environment and Development* (*IIED*) uses a series of case studies to explore and improve the Community-Based Adaptation Framework. It also draws on participatory disaster risk reduction (DRR) approaches, linkages between livelihoods, DRR and climate change, vulnerability identification and planning adaptation activities, monitoring and evaluation, and polices and institutions for community-based adaptation.
- *UKaid and Local Enterprise Partnership (LEP)* provides participatory community toolkits with guidance questions relating to vulnerability and capacity assessment (VCA). These tools are useful for analysis of past hazards.
- *Asian Disaster Preparedness Center (ADPC)* suggests participatory disaster risk assessment (PDRA) as part of its Resource Pack 3.
- *UN-HABITAT* toolkit provides a guide and reference process for local governments and other stakeholders for conducting V&A assessments using a participatory step-by-step process, a checklist of questions designed to cover multiple aspects of the causes and effects of vulnerability and adaptive responses, focus group discussions and consultation workshops with relevant local authorities.
- *Christian Aid* Adaptive Framework builds on DRR concepts and integrates them into a livelihoods approach with a focus on building resilience to climate change. However, it does not provide clear practical guidance or relevant evidence of effectiveness.
- *Oxfam GB* Participatory Risk Assessment (PRA) and Participatory Learning and Action (PLA) tools for participatory capacity and vulnerability assessment (PCVA) include a timeline, seasonal calendar, guidance for focus group discussion and role play, resource mapping, hazard mapping, guidance for gathering information about historical transactions, matrix ranking and scoring, wealth ranking, Venn diagrams, community visioning mapping, and household interviews and storytelling.
- *World Bank* guidelines on mainstreaming adaptation to climate change in agricultural and natural resource management projects suggest using a combination of integrated tools for M&E data collection in adaptation projects. The results of remote sensing for example can be checked and triangulated with information collected from surveys, focus group discussions and/or interviews with local key informants.

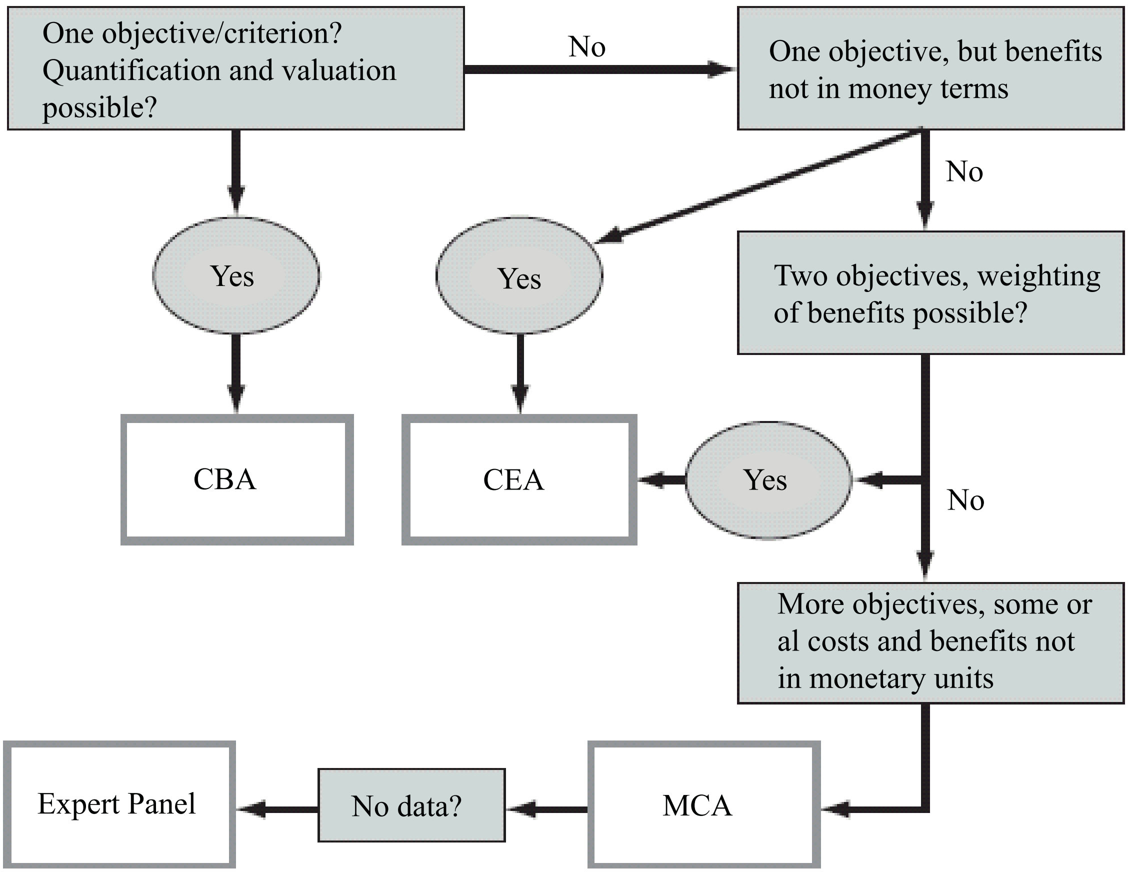
4.4. Other Decision Support Tools (DSTs)

In addition to the complex mathematical models outlined in Section 4.2, and other assessment and risk screening tools for local participatory assessment of V&A, the project team conducted an analysis of vulnerability and adaptation using various decision support tools (DSTs) including multi-criteria analysis (MCA), cost benefit analysis (CBA), and cost effectiveness analysis (CEA).

The selection of the best tools for Cambodia must also be based on the scale and scope of adaptation objectives and measures, and the particular stage the adaptation planning processes have reached. Projects and programmes that are in the formulation stage could benefit more from rapid risk screening tools than from complex analytical tools such as CBA and CEA. The latter might be more useful at later stages of adaptation planning, when results that are more accurate are required for decision-making (Niang-Diop and Bosch 2004).

When assessing the costs and benefits of water management strategies, the three most appropriate approaches are CBA, CEA and MCA. The following sections explain their applicability, ease-of-use, technical requirements and suitability in Cambodia.

Figure 5: Method for Identifying the Best Economic Impact Analysis Tools for Selecting and Prioritising Various Strategies



Source: (Niang-Diop and Bosch 2004: 195)

MCA is a decision support tool applicable in cases where CBA falls short due to its single-criterion approach, particularly where environmental and social costs and benefits cannot be expressed in monetary terms (MK16 Project Team 2013: vi). This is because MCA enables options to be compared and ranked according to a full range of criteria (e.g., environmental, social, technical, economic and financial).

Variations of the MCA approach are available. Existing MCA approaches include the performance matrix, multi-attribute utility theory, linear additive models, analytical hierarchy process, and outranking methods (see DCLG 2009 for more details) (MK16 Project Team 2013: 9). All MCA approaches can help users identify different options and assign relative weights to different criteria. They require judgement in weighting and scoring. The only difference is in how they combine data (DCLG 2009 cited in MK16 Project Team 2013: 9).

The judgment of the decision–making team in establishing a set of objectives and assigning relative weights for each of the performance criteria is a key feature of MCA (MOE et al. 2012b: 31). Using this weighting approach, an overall score for each option is generated, and the option with the highest score can be selected. MCA can also be combined with other assessment approaches such as CBA and CEA to provide a foundation for more informed decision-making (MOE et al. 2012b: 31). .

MCA is a relatively simple tool to grasp and use; but it requires the time, cost, and training Data requirement for an MCA exercise depends on the criteria chosen for evaluation and the indicators and metrics relevant for these criteria (MK16 Project Team 2013: 10).

The Adaptation Decision Matrix (ADM) presents another option. ADM uses a decision matrix and MCA techniques to evaluate climate change adaptation options for their relative cost-effectiveness. ADM can be used to support water resources management and improve water use efficiency (MK16 Project Team 2013: 10). This approach is also useful when important criteria for decision-making cannot be easily expressed in monetary terms.

4.5. Indicators for V&A Assessment

MOE et al. (2012b: xxvii) noted that only a few projects have attempted to understand overall climatic change vulnerability by combining measures of climate exposure, sensitivity and adaptive capacity. A common approach to vulnerability assessment is to aggregate individual indicators into an overall score, referred to as an index. A well-known example of an index that measures vulnerability levels is the Human Development Index (HDI), which combines various indicators such as health status, education level and living standards. The HDI is constructed by standardising scores for these various indicators and assigning each indicator different weights.

The currently available indices all have their limitations, but some are better than others for particular vulnerability contexts or vulnerability assessment purposes. Due to these methodological variations, caution will be exercised in using vulnerability indices to inform decision-making for our selected sites (Barnett et al. 2008). Indices require a coherent model of vulnerability on which the selection of indicators can be based. There are issues to do with the scale of the system to be measured. Larger scales tend to be favoured for their perceived policy relevance; yet the larger the scale, the lower the specificity of the risks and outcomes.

The selection of indicators is challenging due to the availability and quality of data, and the selected model might lead to indicators that are redundant. This implies that indices should use fewer indicators based on complete and highly robust data. Particular attention must be paid to the standardisation of indicators, which can also be problematic, "...particularly as it entails converting nonlinear risks into linear scales. The weighting of indicators is often contentious;

weighting can help reflect the judgments of experts and the values of groups of concern, yet determining the appropriate weighting of indicators is procedurally difficult. Methods of aggregation are also contentious" (Barnett et al. 2008: 107).

In this study, the indicators and indices measuring aspects of climate change vulnerability will be applied on a small scale since they tend to become less meaningful when applied on larger scales, and vulnerability is a context-specific phenomenon rather than a generic condition. For further studies under the project, indicators and indices that measure climate exposure, sensitivity and adaptive capacity can be used to produce maps showing the spatial distribution of vulnerability (see Section 2.2). These maps can be developed collaboratively with inputs from the community representatives having first-hand knowledge, along with expert judgement and modelling results to determine areas with higher or lower levels of vulnerability. These results can be used to identify priority areas for adaptation interventions.

Adger et al. (2004: 101) identified nine key indicators as proxies for national-level assessments of vulnerability to climate change. Variables for each of these nine indicators are presented in Appendix 3. In the Tonle Sap catchments, the indicators should be used to guide understanding about community-based vulnerability and adaptation; therefore, the indicators should be scaled down to local and community level.

5

CONCLUSION AND RECOMMENDATIONS

Information from the desk review and consultations with key stakeholders from national and subnational agencies, and representatives from community-based organisations and locally elected officials (commune and village councillors) was merged to synthesise the key findings and form recommendations for further studies to fill any gaps.

The Cambodian government reports indicate that climate change is real, and by all accounts is already being felt. At the same time, the country is increasingly suffering from the effects of short-term climate variability such as floods, droughts and storms. These facts underline the need to address both climate change adaptation and disaster risk reduction.

Our hypothesis is that changes in the Tonle Sap flood pulse and water regime over the next 30 years are more likely to be caused by infrastructure development, especially hydropower and irrigation dams, and climate variability than by climate change. But the latter will further increase uncertainties that need to be properly mainstreamed into decision-making and policy processes to ensure climate resilience. Water scarcity and socioeconomic tension is intensified by lack of proper water allocation mechanisms, irrigation and crop planning within the catchments. This has reportedly led to recurring conflicts over to access to water between upstream and downstream farmers.

To test this hypothesis, the project needs to apply an integrated approach combining a comprehensive vulnerability and adaptation assessment framework, mathematical modelling, climate scenarios and downscaling (results and interpretation), risk screening and decision support tools. It must also conduct participatory vulnerability assessment and adaptation planning.

The selection, application and cost-effective use of appropriate database, framework tools and methods, and the conduct of community and catchment-level vulnerability and adaptation assessments will eventually lead to recommendations for improved and locally-appropriate site- and context-specific vulnerability adaptation measures in the Tonle Sap Basin catchments.

Data Gaps and Needs Assessment for Site- and Context-specific V&A Assessment

Site-specific and context-specific Vulnerability and Adaptation (V&A) assessments are a key step for anchoring the assessments of climate change impacts to present and future development planning. As vulnerability is a relative measure, measuring it requires an awareness of several technical issues, including reliability of the data, the coverage of relevant dimensions of vulnerability, their sensitivity to change, mapping of indicators, and good alignment between indicators. These technical issues dictate the required quantity and quality of data and the expertise needed to achieve a sound V&A assessment.

Related data and information are needed to understand the boundary and baseline conditions of the selected key assets and their subsets, and to monitor any changes over time. The data and information needs include exposure to current climate hazards, including the frequency and intensity of these hazards, as well as damage caused by their impacts; factors that contribute to vulnerability (sensitivity and adaptive capacity); water security in the face of current climate hazards; and factors that may contribute to long-term vulnerability (institutional, socioeconomic and environmental/climatic projections).

The existing data and information are of different scales and varying quality and therefore must be carefully collated and evaluated. This data should be collected and verified using participatory mapping at the selected study sites.

Despite recent improvement in data and information management in Cambodia, huge data gaps remain. This is one of the key considerations in the selection of the methods and tools for V&A assessment and planning.

Assets can be determined by reference to a variety of sources including the resources of multilateral and non-governmental organisations. As data is obtained from different sources, with collection decisions and processes based on pre-determined standards and methodologies, data handling requires great care and its own appropriate methodology.

The meteorological and hydrological data generated by existing networks in all three selected sites has substantial shortcomings. Data and information in Pursat and Kompong Chhnang are relatively more available and reliable than that in Kompong Thom. The climatic and hydrological data for the three selected catchments and other Tonle Sap catchments are not homogenous, as not all data records were started at the same time or in the same manner, and the hydrometeorological conditions tend to be highly localised.

Vulnerability and Adaptation Assessment Methods and Tools

The decision support methods and tools ranged from complex models developed to assess current and future climate risks, impacts, vulnerabilities and adaptation needs to guidelines on identifying, designing, prioritising and evaluating adaptation measures. Cambodia's experience with decision support tools has been limited.

To address the effects of changes in natural and human systems on vulnerability and adaptation in the three selected catchments Stung Chrey Bak of Kompong Chhnang, Stung Chinit of Kompong Thom, and Stung Pursat in Pursat) in the Tonle Sap Basin, four different types of methods and tools were suggested: climate change impact modelling, hydrological impact modelling, risk-screening and decision support tools, and participatory tools.

Participatory Tools

Given the wide array of adaptation responses that might be required for Cambodia to properly address current and future climate impacts, it is sensible to consider a broad range of tools for future use in the country. The following would help to cover the complete picture: screening climate risks, assessing current and future climate risks, impacts and vulnerabilities, and identifying adaptation options. Moreover, prioritising and implementing adaptation measures at the subnational and/or local level requires participatory evaluation approaches that involve key stakeholders such as community members, vulnerable groups or local decision-makers.

The review of existing participatory methods and tools developed and used by different organisations for V&A assessment was conducted by comparing the sets of best practice criteria listed in Table 1. This exercise revealed that participatory V&A assessment is commonly used by different organisations to empower community members to systematically analyse their problems, suggest their own context-specific solutions and identify how to achieve them. The participatory V&A assessment is also considered a bottom-up approach for identifying appropriate solutions to reduce hazards or risks posed by climate change.

CARE's Climate Vulnerability and Adaptive Capacity (CVAC) assessment and Community-Based Adaptation Toolkits (based on a sustainable livelihoods approach) are considered particularly relevant. The Oxfam GB Participatory Rural Appraisal (PRA) and Participatory Learning and Action (PLA) tools for participatory capacity and vulnerability assessment (PCVA) have many useful components for understanding vulnerability and adaptation capacity.

It is recommended that Mini Study 2 adapts community-based adaptation, CVAC and PCVA and selects and tries other relevant tools that have been developed and have proved useful to other major programmes and organisations in conducting vulnerability and capacity assessments. The UN-HABITAT toolkit for local governments and other stakeholders is also recommended.

Modelling Tools

Models for hydrological, hydrodynamics, and water quality assessment are very important. They can be used to provide quantitative inputs for V&A assessments, and for resilience planning for critical infrastructure. It is important to select the most relevant and appropriate models that cover the following aspects: i) physical processes; ii) availability and quality of data; and iii) ability to generate results with a good degree of certainty under extrapolated conditions.

PRECIS (Providing REgional Climates for Impacts Studies) has been applied as a climate change impact model in Cambodia. Therefore, there is no need to repeat this exercise. Recommended is the use of downscaled national climate data (temperature and precipitation) or the existing results from PRECIS in respect of the project sites in Kompong Chhnang, Pursat and Kompong Thom (using the resolution of 0.2 x 0.2 degree (equivalent to about 22 x 22 km).

Appendix 2 provides a description of the modelling tools and their selection. This study recommends that the project team apply the following tools:

Rainfall-runoff models can be used to provide discharge data. These models convert statistical information on rainfall into statistical information on river discharges. If possible, the simulation of series of individual events should be replaced by the simulation of long time series. The Soil and Water Assessment Tool (SWAT) and a newly developed Unified River Basin Simulation (URBS) model will be used. The SWAT model can be run to identify suitable adjustment methods by comparing outputs with adjusted data from regional climate models and with observed climate data for 1985-2000.

Hydrological routing models – Integrated Quantity-Quality river basin simulation Model (IQQM) and simplified EXCEL Spreadsheets – will be used for simulating all the processes and rules associated with the simplified description of the movement of water through a river system.

Following the application of SWAT and IQQM, ISIS is recommended for predicting flood levels.

The Basin Simulation Model (BSM) can be used as well. The purpose of the BSM is to simulate possible future water resource development to estimate the effects of water availability for different water users at different times throughout the river basin.

New hydrological models – the Mekong River Commission Tool Box, the Integrated Water Resources Management (IWRM) model, and eWater – are recommended for training purposes, depending on local circumstances, as they require complex data, are not yet stable, and are not currently suitable for Cambodia.

Other Decision Support Tools (DSTs)

In addition to the above complex mathematical models and other assessment and risk screening tools, the project team are going to conduct adaptation planning using various decision support tools including Multi-criteria Analysis (MCA), Cost Benefit Analysis (CBA), and Cost Effectiveness Analysis (CEA).

The selection of the best tools for Cambodia must also be based on the scale and scope of adaptation objectives and measures, and the particular stage of the adaptation planning process. Projects and programmes already at the formulation stage might benefit from rapid risk screening tools instead of complex economic analysis tools such as CBA and CEA. The latter might be more useful at later stages of the adaptation planning process, when more accurate results are required to provide a basis for decision-making.

MCA is applicable in cases where a single-criterion approach such as CBA falls short, particularly where environmental and social component costs cannot be expressed in monetary terms. MCA is a relatively simple tool to grasp and use; however, the time, cost and training required depend on the specific methodology used. Generally, minimal training is required. All available MCA techniques rely on expert judgment to a certain extent.

The Adaptation Decision Matrix (ADM) approach presents another option. This approach uses a decision matrix and MCA techniques to evaluate the relative cost-effectiveness of adaptation options. Since adaptation can entail improving water use, distribution and allocation, ADM can find applicability in supporting water management. This approach is also useful when important criteria for decision-making cannot be easily expressed in monetary terms.

Indicators for V&A assessment

A well-known example of an index that measures vulnerability levels is the Human Development Index (HDI). It combines various indicators such as health status, education level and living standards. The HDI is constructed by standardising scores for these various indicators and assigning each indicator different weights.

The selection of indicators is another difficulty because the ideal data might not be available, and the data that is available could be of questionable quality. It is therefore recommended that indices should encompass fewer indicators based on widely available and robust data.

The standardisation of indicators can also be a problem, particularly as it entails converting nonlinear risks into linear scales. The weighting of indicators is often contentious.

In this study, the indicators and indices for measuring climate change vulnerability will be applied on small scales since they tend to become less meaningful when applied on larger scales, and vulnerability is a context-specific phenomenon rather than a generic condition.

For further studies conducted under this project, indicators and indices that capture climate exposure, sensitivity and adaptive capacity can be used to produce maps showing the spatial distribution of exposure, sensitivity and capacity. In the Tonle Sap context, the indicators should be used to advance understanding on community-based vulnerability and adaptation. Given this, national-level indicators should be downscaled to local and community levels.

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APPENDICES

Appendix 1: Climate Change and Hydrological Models

1.1. Climate Change Models

In 2002, the National Climate Change Technical Team, led by the Ministry of Environment (MOE), used global warming scenarios, i.e. the Special Report on Emissions Scenarios (SRES) A2[5] and B1 (policy) (IPCC 2000), for predicting the impacts of climate change on Cambodia (MOE 2002: 34). Climate simulations were performed using two general circulation models (GCMs) – CCSR[6] and CSIRO[7] – applying correction factors to account for significant differences between climate model data and observed data. The project team members with expertise in climate modelling recommended that there was no need to run the climate models again, given that they have already been applied at both national and regional scales. Therefore, it was only necessary to downscale climate model data to the project sites.

PRECIS Climate Model

The most widely applied dynamical downscaling model in the Mekong Region is PRECIS (Providing REgional Climates for Impacts Studies). PRECIS is an atmospheric and land surface model (www.metoffice.gov.uk/precis/) It can be used for modelling global meteorological flows and thermodynamics: dynamical flow, atmospheric sulphur cycle, clouds and precipitation, radioactive processes, the land surface and the deep soil.

Climate projections are produced by GCMs. For local and regional scales, the relatively low spatial resolution of GCM outputs (100-300 km) needs to be downscaled. This is done using either statistical or dynamical downscaling.

Table A1: Strengths and Weaknesses of Dynamical Downscaling

Strengths	Weaknesses
Based on physical modelling	Computationally resource intensive
Not dependent on an assumption that current local and large-scale climate relationships are maintained into the future (which is the case in statistical downscaling)	Generates numerical errors and artefacts as well as biases that need to be corrected
Not bound to observation points (which is the case in statistical downscaling)	Choice of boundary conditions can have a strong impact on any regional model performance/ results (global model biases and errors are propagated into the downscaling results)
Enables testing of the impacts of different parameterisations and model assumptions on results	The scale of convective rainfall is difficult to reach with the usual available computer resources
	The capability of the dynamic downscaling method to predict climate more accurately than the statistical downscaling method is not proven

5 IPCC Special Report on Emissions Scenarios (SRES) presents four qualitative story lines that yield four "families" of scenarios: A1, A2, B1 and B2. The scenario of interest, A2, corresponds to a storyline of high population growth with slower per capita economic growth and technological change.

6 Center for Climate Research Studies (Japan)

7 Commonwealth Scientific and Industrial Research Organisation (Australia)

Table A2: Strengths and Weaknesses of Statistical Downscaling.

Strengths	Weaknesses
Allows downscaling activities to be grounded in actual observations	Sensitive to choice of predictors (e.g. rainfall predictors can be upper-level humidity, geopotential height or 24 hour cumulative precipitation), and therefore to the capability of GCMs to simulate these predictors
Computationally efficient	Cannot simulate any systematic changes at regional level
Can be applied to any consistently observed variable	Some methods tend to under-predict temporal variance
Can be used to generate a large number of realisations in order to quantify uncertainty	Based on an unverifiable assumption that relationships between large-scale features and local climate remain stationary under future change
Requires only monthly or daily GCM outputs	
Can relate GCM outputs directly to impact-relevant variables not simulated by climate models	

Although dynamic downscaling must be applied with caution, it can be a useful tool for understanding local atmospheric physics and changes. The application requires correction of unrealistic values and model biases, and is based on historical meteorological data.

1.2. Hydrological Models

Over the last decade, with the support of the Mekong River Commission (MRC) through the development of the Decision Support Framework (DSF), progress has been made in developing hydrological models. The DSF involves rainfall-runoff models based on the Soil and Water Assessment Tool (SWAT), reservoir operation and hydrological routing models based on an integrated water quantity and quality simulation model (IQQM) (covering water resources including irrigation and hydropower), and the hydrodynamic model for the Mekong Delta based on ISIS (1D hydrodynamics and sediment transport). In addition, the MRC's Flood Management and Mitigation Programme (FMMP) has led the modelling of flood forecasts in respect of the main Mekong River and its tributaries, based upon the Unified River Basin Simulator (URBS). Some of these tools are discussed below.

MRC Toolbox and World Bank IWRM Model integrates a significant number of process models that are normally implemented separately. However, many models integrate some submodels: crop models, for example, often include at least rudimentary hydrological models coupled with plant growth models.

Model characteristics	Brief description
Name	MRC Toolbox and World Bank Integrated Water Resources Management (IWRM) model
Corresponds to Cambodia's needs and concerns	Yes; flooding, crops, irrigation, reservoirs, sediment, water quality etc.
Data needs and applicability with limited available data	Designed for limited data, especially sparse hydrometeorological data and limited soil data; developed in the Mekong for available Mekong data
Ease of use	Map-based graphical user interface (GUI) is easy to use; need to learn only one interface; auto-calibration; automatic production of indicators and GIS maps; strong GIS support; takes time to master all options
Balanced learning curve	Basic use learned in less than a day; understanding of natural processes and analysis of model outputs takes time
Level of regional application	High, designed and developed for Mekong conditions
Accessibility including software and training costs	Free of charge; training with development partner support, or by MRC
Level of integrated and holistic approach	Very high
Quantified, accurate and relevant outputs	Yes; has been verified in a large number of applications
Ability to represent natural systems and human impact on them	Yes; physically and biologically-based description of natural systems and processes; represents topography, river systems, vegetation, crops, water management, and so on, in much higher detail than any other model, for instance whole Mekong Basin 1 km x 1 km resolution; high temporal representation enables simulation of e.g. flash floods
Level of existing applications and applicability for climate change assessment	By far the widest use for climate change studies in the Mekong region; designed for processing climate and climate impact data including dynamic interpolation and automatic production of indicator maps

Integrated Water Resources Management (IWRM) 3D is a detailed hydrodynamic and water quality model that has been developed for the MRC Toolbox. It was originally developed for the Tonle Sap, and has since been applied in many other areas of the Mekong including the entire Lower Mekong Basin. The main use has been hydropower impact analysis for the lower Mekong floodplains, covering flooding, salinity intrusion, water temperature, sediment input, erosion, water quality and primary and fisheries production. The model is an appropriate tool for the analysis of lakes, reservoirs, rivers, floodplains and coastal areas. It works under the same user interface, geographical information systems (GIS), data processing and visualisation platform as the IWRM watershed model.

Model characteristics	Brief description
Name	MRC Toolbox Integrated water Resources Management (IWRM) 3D Model
Corresponds to Cambodian needs and concerns	Yes; floods and flooding, upstream development impacts, fisheries production, water quality, river channel erosion, floodplain impacts, etc.
Data needs and applicability with limited available data	Designed for limited data especially sparse hydrometeorological and land cover data
Ease of use	Map-based user interface easy to navigate but extended model has many options; need to learn only one interface together with the watershed IWRM model; setting up of a 3D hydrodynamic model requires some skill especially for model stability
Balanced learning curve	Basic use learned in less than a day; understanding of natural processes and analysis of model outputs takes time; also setting up a new model requires basic understanding of hydrodynamic modelling
Level of regional application	High, designed and developed for Mekong conditions
Accessibility including software and training costs	Free of charge; training with development partner support, or by MRC
Level of integrated and holistic approach	High
Quantified, accurate and relevant outputs	Yes; has been verified in a large number of applications
Ability to represent natural systems and human impact on them	Yes; physically and biologically-based description of natural systems and processes; very high spatial and temporal resolution
Level of existing applications and applicability for climate change assessment	Some: Mekong floods, sea level rise, salinity intrusion, Tonle Sap vegetation zones

The eWater Water Cooperative Research Centre is developing an integrated modelling system, which is the next generation of software tools for river planning, management and operation (Rassam et al. 2012: 4). The modelling of groundwater and surface water (GW-SW) interactions in river system models is still very much in its infancy. The significant time-scale difference between surface water and groundwater processes is a challenge. To model GW-SW interactions in a river system requires accounting for these time lags, which often proves to be extremely challenging (Rassam et al. 2012: 4).

There is little discussion in the literature about what constitutes best practice modelling in this field. As such, there is no consensus on the modelling of GW-SW interactions in river system models (Rassam et al. 2012: 4).

Unified River Basin Simulation (**URBS)** is a mathematical modelling tool for describing rainfall-runoff processes in a catchment. It was introduced to the Mekong countries, including Cambodia, in 2007 at the MRC Regional Flood Management and Mitigation Centre (RFMMC) (MK16 Project Team2013: 4). URBS combines in the modelling process the rainfall-runoff and runoff-routing components. Its users can configure the model to match the individual catchments' characteristics by using the GIS package known as Catchment SIM (Pengel et al. 2007: 1).

Integrated Quantity-Quality Model (IQQM) can be used for simulating all the processes and operational rules to describe the movement of water (flow) through a river system (Hameed and O'Neill n.d.: 1958). IQQM can be configured for river systems with single and/or multiple reservoirs that operate in series or parallel. The model applies hydrologic flow routing for the simulation of the different ranges of flow conditions (Hameed and O'Neill, n.d.: 1958).

Model characteristics	Brief description
Name	Integrated Quantity and Quality Model (IQQM)
Description	1. Assesses impact of interventions such as storage structures or increased irrigation development on flows elsewhere in the river catchment 2. Assesses impact of externalities such as climate change on water availability and flows in the river catchment
Appropriate use	Mekong River Basin
Scope (sector/location)	Water allocation in the Lower Mekong
Key outputs	Discharge
Key inputs	Flow, rainfall, evaporation – by subcatchment Irrigation area, crop type, crop calendar, crop pattern, reference irrigated water per hectare per second – by subcatchment Hydropower data and related information Reference water use per capita per day River system, subcatchment in GIS format
Key tools	
Ease of use	User-friendly graphical user interface
Training required	No need for Department of Hydrology and River Works (DHRW)
Training available	Can be done by DHRW
Computer requirements	Windows XP 7
Documentation available	Yes: Mekong River Commission Secretariat (MRCS), Cambodia National Mekong Committee (CNMC) and DHRW
Applications in Cambodia	Any river catchment including around the Tonle Sap Lake
Applications in the project sites (three provinces around the Tonle Sap)	Applicable in all study areas
Strengths	Water use for irrigation
Weaknesses	No support from developer
Relevance to climate change and water	Can be used

Simplified Excel Spreadsheet for water balance computation has been used by Department of Hydrology and River Works (DHRW) staff to deal with water balance computation in the river basin, taking irrigation systems into account. These spreadsheets are very useful in computing evapotranspiration and crop water requirements, and for confirming the security of river basin water resources and proposing areas for new irrigation development projects, and so on.

Soil and Water Assessment Tool (SWAT) is a physically based, distributed agro-hydrological model used for the assessment of water resources and water quality on a catchment scale. It operates on a daily time step basis and is designed to predict the impact of management on water, sediment and agricultural chemical yields in un-gauged basins (Arnold et al. 1998). It is capable of long-term continuous simulations in large complex catchments with varying soils and management conditions.

Model characteristics	Brief description
Name	Soil and Water Assessment Tool (SWAT)
Description	A physically-based, distributed, agro-hydrological model that operates on a daily time step basis and is designed to predict the impact of management on water, sediment and agricultural chemical yields in un-gauged basins
Appropriate use	Assessment of water resources and water quality on a catchment scale
Scope (sector/location)	Micro to macrocatchment scale
Key outputs	Water discharge, sediment, nutrients (N&P), pesticides
Key inputs	Meteorological data (rainfall, temperature, relative humidity, wind speed, solar radiation), Land-use (management practices), Digital Elevation Model (DEM) Soil (different layer depth)
Key tools	ArcGIS (3D Analyst and Spatial Analyst), ArcSWAT, Microsoft Office
Ease of use	Complicated
Training required	Yes, ArcGIS and ArcSWAT operation, remote sensing, data input, running, and interpreting.
Training available	Yes, training courses on theory and practice of GIS, remote sensing, hydrology, ArcGIS and ArcSWAT.
Computer requirements	Pentium IV processor or higher (>2 GHz), 1 GB RAM minimum, 500 Mb free memory minimum on hard drive
Documentation available	Yes: www.swat.tamu.edu/
Applications in Cambodia	Tonle Sap Basin by MRC (also in Chrey Bak catchment, Kompong Chhnang province by ITC), Sesan, Srepok, and Sekong (3S) catchments by University of Canterbury
Applications in project sites	Very challenging to have sufficient data for model calibration in particular rainfall data availability which is not representative for larger catchment

Strengths	Capable of continuous simulations in large complex catchments with varying soils and management conditions over long periods Uses readily available inputs, has the capability of routing runoff and chemicals through streams and reservoirs, allowing the addition of flows and the inclusion of measured data from point sources Can analyse small or large catchments by making discretisation into sub-basins, which are then further subdivided into hydrological response units with homogeneous land use, soil type and slope Embedded within GIS systems it can integrate various spatial environmental data, including soil, land cover, climate and topographical features
Weakness	Data hungry and requires strong hydrological knowledge
Relevant to climate change and water	Prediction of water availability on a catchment scale Option to adjust climate change data input (change in percentage of rainfall and CO_2)

ISIS is river modelling software used for flood risk management first developed in the 1970s as Halcrow's ONDA and HR Wallingford's FLUCOMP, LORIS and RIBAMAN software. It is a suite of modular software solutions used for simulating water flow, hydrology, water quality changes and sediment transport in rivers, floodplains, canals, estuaries, catchments and urban areas.

Model characteristics	Brief description
Name	ISIS river modelling software
Appropriate use	An analysis tool for flood risk mapping, flood forecasting and other aspects of flood risk management analysis. It is used by the Environment Agency, Office of Public Works, Scottish Environment Protection Agency, Mekong River Commission
Scope (sector/ location)	A suite of modular software solutions used for simulating water flow, hydrology, water quality changes and sediment transport in rivers, floodplains, canals, estuaries, catchments and urban areas.
Key outputs	From calculating simple backwater profiles to modelling entire catchments: applications include flood risk assessments, catchment management plans, flood alleviation scheme designs, river engineering and irrigation schemes, environmental impact assessments, water pollution management, flood risk mapping, integrated modelling, surface water management plans, catchment and floodplain development. ISIS Mapper can be used to build hydraulic models, analyse results, and visualise model outputs

Key inputs	Configuration of system (can use GIS layers for background) and component capacities and operating policies Water demand: spatially explicit demographic, economic, crop water requirements; current and future water demands and pollution generation Economic data: water use rates, capital costs, discount rate estimates Water supply: historical inflows at monthly time steps; groundwater sources. Scenarios: reservoir operating rule modifications, pollution changes and reduction goals, socioeconomic projections, water supply projections Water level: observed data Capacity: floodplain modelling and mapping, rainfall run-off modelling and flood forecasting.
Key tools	A robust user interface which is extremely user-friendly Integrated GIS environment (ISIS Mapper) at no additional cost Fully customisable engines with a choice of Alternating Direction Implicit (ADI), Total Variation Diminishing (TVD) or FAST or solvers Industry standard 1D (ISIS Professional) and 2D (ISIS 2D) models Hydrology modules including the UK standard Flood Estimation Handbook (FEH) and Revitalised Flood Hydrograph (ReFH) rainfall-runoff methods Multiple productivity tools, including a model health checker and results extractor Hydraulic features including total energy junction, blockage unit and flat-V weir
Ease of use	Relatively easy; requires significant data for detailed analysis; ISIS professional graphical user interface is extremely user-friendly
Training required	Moderate training and/or experience in resource modelling is required for effective use
Training available	Wide range of courses on theory and practice of hydrology, hydraulics and flood risk management, and GIS. Training courses run by experts in the development and application of ISIS (www.halcrow.com/training)
Applications in Cambodia	Used popularly in Cambodia for predicting flood
Applications in the project sites (3 provinces of Tonle Sap)	MRC has been using ISIS for over 10 years. It includes more than 5000 nodes and extends from Kratie province and the Tonle Sap Lake to the Mekong Delta, and would be selected as the most appropriate modelling tool for the project sites
Weaknesses	Requires hydrological modelling capacity and experience Strong expert support is needed in its development and application Software products that link to ISIS include TUFLOW and Flood Viewer, which are costly
Relevance to climate change and water	Relevant to climate change and water resource management: in constant use for a wide range of applications including flood mapping, flood risk assessments, design of flood defences and real-time flood forecasting

Tank is a very simple model, composed of four tanks laid vertically in series (see Sugawara 1995). It demonstrates the movement of water over the land surface, where precipitation runs off into streams, small rivers and to then bigger rivers. The hydrology of a catchment or drainage basin, from precipitation to stream discharge (in cubic metres per second) at the river cross sections, can be estimated in a series of interlinked processes and storages. The modellers describe the catchment processes mathematically and consider storages as reservoirs (tanks), for which water budgets or water balance are derived (Shaw 1994: 369).

Model characteristics	Brief description
Name	Tank
Appropriate use	Assessment of stream discharge at the lowest outfall
Scope (sector/ location)	Drainage basin
Key outputs	Average runoff at the outlet
Key inputs	Basin area, area rainfall, evaporation, and a set of model coefficients
Key tools	Algorithm in Fortran
Ease of use	Ease of application and a small amount of required input data
Training required	Yes, hydrology, basin river system, geography and remote sensing
Training available	Yes, hydrology, basin river system, model operation including data input, analysis, and interpretation
Computer requirements	Normal computer
Documentation available	Yes; M. Sugawara, "Tank Model", in V. J. Singh (ed.) (1995), *Computer Models of Watershed Hydrology*, www.cof.orst.edu/cof/fe/watershd/fe537/labs_2007/Catchment_scale/RR-Model/TankModel.pdf
Applications in Cambodia	Has been applied to the 12 sub-basins of the Tonle Sap to investigate its performance, and to evaluate water availability in the sub-basins
Applications in the project sites	Applied to the Chrey Bak catchment and Pursat and Chinit sub-basins
Strengths	Simplicity, ease of application, requires a small amount of input data and generates good results
Weaknesses	Difficult to calibrate, lumped model gives results only at the outlet
Relevance to climate change and water	Rarely applied in climate change measurements and assessments

The **Hydrologic Modelling System (HMS)** was developed at the Hydrologic Engineering Centre (HEC) within the US Army Corps of Engineers beginning in 1992. It is used to simulate precipitation-runoff processes of dendritic (branching like a tree) stream networks, representing the watershed flow system.

Name	Hydrologic Engineering Centre/ Hydrologic Modelling System (HEC-HMS), a precipitation-runoff modelling system
Appropriate use	Large river basin water supply and flood hydrology, and small urban or natural watershed runoff processes. Hydrographs can be used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanisation impacts, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation
Scope (sector/ location)	Generalised modelling system capable of representing many different watersheds
Key outputs	Hydrographs
Key inputs	Digital Elevation Model (DEM) of watershed, hydrometeorological data (precipitation), land use maps, soil information
Key tools	The software itself and HEC-GeoHMS
Ease of use	Graphical user interface makes it easier to use
Training required	Yes: how to input data, how to weight data, how to analyse data (run the model), and how to interpret results
Training available	From Hydrologic Engineering Centre, US Army Corps of Engineers, and "Introduction to HEC-HMS", www.ce.utexas.edu/prof/maidment/gradhydro99/hmwk1/hmsintro.htm
Documentation available	With the program, or at www.hec.usace.army.mil/software/hec-hms/documentation.aspx
Applications in Cambodia	Simulated changes in water flows of the Mekong River from potential dam developments and operations on the Sesan, Sekong and Srepok tributaries
Applications in the project sites (3 provinces in the Tonle Sap)	None
Strengths	• Watershed Physical Description: capable of describing watersheds using sub-basins, reach, junctions, reservoirs, diversions, sources and sinks • Provides variety of methods to simulate infiltration losses: transforming excess precipitation into surface runoff; representing base flow contributions to sub-basin outflow; simulating flow in open channels; and representing water impoundments • Includes precipitation, evapotranspiration and snowmelt • Hydraulic Simulation: the time span of simulation controlled by control specifications including start date and time, end date and time, and a time interval • Parameter Estimation: most parameters for methods included in sub-basin and reach elements can be estimated automatically using optimisation trials • Analysing Simulation: currently, only the depth-area analysis tool is available • GIS Connection: using HEC-GeoHMS extension to connect ArcGIS with HEC-HMS, it can be used to create basin and meteorological models for use with the program
Weaknesses	1. The mathematical models are not connected, they work separately 2. Flow presentation can be applied to dendritic stream networks only; it does not allow for backwaters in the stream network
Relevance to climate change and water	Assessment of hydrologic impacts of climate change using downscaled scenarios

Appendix 2: Detailed Participatory Methods and Tools

2.1. Vulnerability and Capacity Assessment (VCA)

The vulnerability and capacity assessment (VCA) is a basic approach to generate or improve understanding of: 1) climate change impacts on selected location (spatial) and on selected time scale (temporal); 2) vulnerability of ecosystems and livelihood activities to change; and 3) adaptation capacity in terms of what established mechanisms/capabilities help communities and households to adapt to climate (and non-climate) impacts (Andrade Perez et al. 2010 cited in Bobenrieth et al. 2012: 7).

VCAs also provide opportunities to engage stakeholders, from local communities and subnational authorities to national agencies, in research, analysis and mutual learning in selecting and facilitating adaptation options. These tools have been implemented in Cambodia's coastal provinces, Koh Kong and Kampot (Bobenrieth et al. 2012: 8).

The design of VCA and associated tools was influenced by a review of V&A assessments conducted for the Building Coastal Resilience (BCR) project. The BCR experience in Thailand of VCAs conducted by the Sustainable Development Foundation (SDF) was shared with the International Union for Conservation of Nature (IUCN) in Cambodia (Morgan 2011 cited in Bobenrieth et al. 2012: 13). VCA could be used by our project team as a participatory investigative tool to capture i) key elements of climate change vulnerability (hazard, sensitivity and adaptation capacity, ii) major livelihoods, natural resources (water security) and land use, and iii) historical trajectories of extreme climatic events and how people manage to mitigate their impacts (Bobenrieth et al. 2012: 8).

The VCA toolkit includes:

- Seasonal calendar: to review the annual distribution of livelihoods, natural resources and land use, comparing these with the variation, or fluctuation, in climate hazards that are correlated with a season.
- Historical matrix: to explore prior climate events and/or issues within the community and mechanisms implemented to cope with them.
- Vulnerability matrix: to score or rank climate and non-climate hazards and impacts against livelihoods, natural resources and land use.
- Hazard mapping: to map the occurrence of climate and non-climate hazards over relevant areas and natural resources/ecosystems within the community.

2.2. Vulnerability Reduction Assessment (VRA)

Vulnerability reduction assessment (VRA) is a tool and process for participatory impact assessment. VRA focuses on understanding how climate change is currently, and will in the future; affect the lives and livelihoods of targeted communities. It examines hazards, sensitivity and adaptive capacity with a view to building resilience (UNDP 2012). A Guide to the VRA, developed by Doesh et al. (2008), offers users and practitioners a step-by-step guide through the VRA process. UNDP Cambodia applied it in the Cambodia Community-Based Adaptation Programme (CCBAP) in the 21 target provinces across the country. Practitioners have found the methodology complex and have not been able to unlock its potential to establish a comprehensive baseline of V&A capacity in communities, or to design project activities based on it (UNDP 2012).

The VRA methodology is one of many tools that can assist development practitioners to understand the implications of climate change for the livelihoods of local communities. The VRA has the benefit of being useful throughout the project cycle; at the design stage of a project it guides practitioners in designing effective activities and determining what outcomes the project should aim to achieve. It is particularly useful for local NGOs and community-based organisations, which are more inclined to liaise directly with their target communities before or during proposal design. More details of the method can be found in the Guidebook for Practitioners Implementing the Vulnerability Reduction Assessment (UNDP 2012).

2.3. Social Impact Monitoring and Vulnerability Assessment (SIMVA)

The Social Impact Monitoring and Vulnerability Assessment (SIMVA) was applied to consider complex changes in the Lower Mekong River Basin's aquatic ecosystems, and to provide data and information on social vulnerability (particularly food and livelihood vulnerability) linked to changes in water resources (agriculture, aquaculture, fish, other aquatic animals and plants) (MRC 2010d). The SIMVA study has objectives to provide regular information about the status of, and trends in, the social conditions of the people living in the Basin. It establishes social impact indicators that reflect current socioeconomic conditions and the extent of people's dependence on water resources, since the relationship between these two factors determines people's vulnerability to changes in water resources.

Its long-term monitoring is then designed to 1) identify any significant changes in people's access to water resources, 2) link these changes to their levels of vulnerability, and 3) serve as an indicator of any potentially significant social impacts or the need for precautionary measures (MRC 2010d: 3).

A detailed explanation of the methods used to collect the necessary information is given in the SIMVA Technical Guidelines on Social Impact Monitoring and Vulnerability Assessment (MRC 2010 cited in MRC 2010d: 5). Following is a summary of the main methods used in the implementation of SIMVA in the Lower Mekong countries, as reported in MRC (2010d: 5).

A. **Quantitative household survey:** households were randomly selected from 17 randomly selected villages (20 interviews per village). The interviews were administered using a highly structured questionnaire. All 1360 household interviews were conducted within 15 km of the Mekong and its dependent wetlands. The study sites were, from north to south, Chiang Saen and Udon Thani in Thailand, Champasak in Laos, Pursat and Siem Reap in the Tonle Sap area of Cambodia, and the freshwater zone of the Mekong Delta in Vietnam.

B. **Qualitative data collection:** In each country, detailed qualitative data was collected from key informants and focus group discussions in four of the 17 villages. This was achieved through a series of participatory research events designed to shed light on trends in access to water resources (broadly defined as all aquatic and other water-dependent natural resources) and how dependence on such resources related to the socioeconomic development of the area. The tools were wide-ranging and included resource mapping, historic time lines, seasonal calendars, transect walks, focus group discussions and key informant interviews.

C. **Secondary data collection:** National experts conducted a review of secondary data sources, focusing on those indicators that shed light on the extent of people's potential to build their resilience or to embrace change (e.g. education, employment and availability of services) or the degree of their basic vulnerability (e.g. child malnutrition and mortality, and lack of services).

D. Mapping: GIS technology was used to determine the population living close to the Mekong, along "corridors" of 5, 10 and 15 km on either side of the mainstream. The GIS experts also produced a series of maps using secondary data as well as maps of the location of the research sites.

2.4. Climate Vulnerability and Capacity Analysis (CVCA)

Climate Vulnerability and Capacity Analysis (CVCA) can be a useful tool in understanding the implications of climate change for the lives and livelihoods of the people. The approach combines local knowledge with scientific data in the assessment process to build people's understanding about climate risks and adaptation strategies. It also provides a framework for a multi-stakeholder dialogue within communities and between communities and other stakeholders. It should form a solid foundation for identifying practical strategies for community-based climate change adaptation (CARE 2009: 1).

The CVCA Handbook presents a set of guiding questions for collecting and analysing information at national, local and household/individual levels(CARE 2009: 2). The CVCA is designed to feed into and strengthen planning processes by providing vital, context-specific information about the impacts of climate change and local V&A. The process of gathering, analysing and validating this information promotes dialogue within communities, and between communities and other stakeholders.

CARE (2009: 2) reported that the main objectives of the CVCA were to:

> *Analyse vulnerability to climate change and adaptive capacity at the community level*: The CVCA is a methodology for gathering, organising and analysing information on the vulnerability and adaptive capacity of communities, households and individuals. It provides guidance and tools for participatory research, analysis and learning. It also takes into account the role of local and national institutions and policies in facilitating adaptation.
>
> *Combine community knowledge and scientific data to yield greater understanding about local impacts of climate change*: One of the challenges of working at the local level on climate change adaptation is the lack of scaled-down information on impacts. This is coupled with inadequate data and information on weather and climate predictions. The process of gathering and analysing information with communities serves to build local knowledge on climate issues and appropriate strategies to adapt. The participatory exercises and associated discussions provide opportunities to link community knowledge to available scientific information on climate change. This helps local stakeholders to understand the implications of climate change for their livelihoods, so that they are better able to analyse risks and plan for adaptation.

2.5. Strengths and Weaknesses of the Participatory Methods and Tools

2.5.1. Generic Strengths and Weaknesses

Many methods and tools are in place for conducting vulnerability and adaptation (V&A) assessment, especially stakeholder tools. However, there is limited guidance on how to select the most appropriate approaches for a given location, and no single approach is sufficient in itself to successfully support adaptation planning – each contributes a small piece of the puzzle (MRC 2010b: vii-viii).

A need has been identified for a more holistic approach where the impacts on the Lake system at different temporal and spatial scales are assessed comprehensively (AIT-UNEP RRC.AP 2011: 112). A study conducted by AIT-UNEP RRC.AP (2010: v) recommended as a first step the establishment of quality, user-friendly climate data, integrated with hydrological and weather features and oriented towards application at national and local levels. This would support the improvement of climate change scenarios and projections.

No applicable system to integrate climate and weather forecasting with hydrological features for national, provincial and community use, as one element, exists (AIT-UNEP RRC.AP 2010). When selecting approaches for adaptation planning, the MRC (2010b: 61) recommends that the following aspects are taken into consideration:

1. The data that is available and what other data may be needed
2. The skills and experience needed to apply the methods and tools
3. The simplest tools that are available and that can provide the required outputs
4. The time available and the time needed to implement the methods and tools.

Because experience in applying these methods and tools is rarely documented, a mechanism for allowing these experiences to be shared across communities, countries and regions would be useful (MRC 2010b: 61).

2.5.2 Strengths and Gaps in Participatory Methods and Tools

There is, however, confusion among various organisations over the terms used to describe participatory approaches, and "participatory vulnerability and adaptation" (PVA) assessment is not the only one used. For example, it has been defined as "vulnerability and capacity assessment" (VCA) by CARE International, "participatory vulnerability and capacity assessment" (PVCA) by Oxfam, and "community vulnerability and adaptation assessment and action" by the Secretariat of the Pacific Regional Environment Programme/Canadian International Development Agency (SPREP-CIDA). It has, however, been commonly used as an effective tool to empower poor people and communities to analyse their problems and suggest their own solutions.

All PVA methods and approaches have been amended to build on the early works of participatory rural appraisal (PRA). Some organisations have mainstreamed and integrated DFID's livelihood framework of analysis (e.g. natural, physical, human, financial and social capitals) into PVA approaches and tools. These methods and tools provide an effective resource for understanding local perceptions and creating awareness of hazards or risks and trends, current livelihood capitals, and resources for building local resilience to climate change.

However, the processes of identifying vulnerability and adaptive capacity are unlikely to be the same in that some organisations encourage local communities to start analysis of current adaptive capacity first and then vulnerability in terms of exposure to climate change, while others start with project design, planning and capacity building to reduce risks posed by climate change. The challenges in applying these methods and tools are to some extent associated with insufficient monitoring of progress, which is essential for effective adaptation planning. There is almost no evidence that these PVA approaches and tools have attempted to integrate secondary data and information on climate change, such as conventional climate change projections, into the results of community participatory assessment for the target communities.

The PVA Assessment Process

The approaches and methodologies of PVA assessment have been developed based on the earlier works of participatory rural appraisal (PRA) methods, natural disaster-risk assessment and DFID's sustainable livelihoods framework. The core aim of these approaches is to obtain information about people's livelihoods and daily existence at community level through their active participation (Chambers 1994). However, it needs to be conducted with empathy and the intent to collect information rooted with people within their communities, to foster their active participation in the process, and to provide the basis for them to discover their own means to solve their difficulties. The PRA approach has been mainstreamed into the UK Department of International Development (DFID) livelihood framework, incorporating a wide range of tools for rural and urban development (Carney 1999). The DFID livelihood framework emphasises the varying access of households to bundles of capitals summarised as the natural, physical, human, financial and social capitals necessary for adaptive capacity and resilience, particularly to climate change, and livelihood success. The PVA assessment tools then linked most of these capitals to factors such as trends in climate or commodity prices, and shocks such as the impacts of natural hazards.

The practice of emergency response planning and preparedness must involve the participation of the people affected, through development. This has been supported by building community capacity through VCA based on the commitment not to treat the people affected as helpless victims but as important agents in their own recovery, and whose capacities should be acknowledged as a source of strength and resilience. While most PVA approaches are linked mainly to recovery, it is apparent that the disaster risk reduction process can be adapted to disaster preparedness or adaptation planning and collective action at the community level.

2.6. Comparison of Practical Guidance on Tools for V&A Assessment by Different Organisations

Practical Guidance on the Use of Participatory Tools									
Vulnerability components		CARE	UKaid & LFP	IIED	DFID-SLF	UNDP APF	HABITAT	ADPC	Oxfam GB
Exposure	Seasonal calendar	x			X			X	X
	Historical timeline	x						X	X
	Rain calendar			x					
Sensitivity/Impacts	Mental model			x					
	Hazard/risk mapping	x	X					X	X
	Hazard trend analysis		X						
	Hazard ranking		X					X	X
	Hazard impact ranking		X					X	X
	Transect walk								X
	Climate impact livelihood matrix		X						
	Participatory scenario development			x					
	Cross-impact analysis					X			X
Adaptive capacity	Social mapping				X			X	
	Resource mapping		X		X			X	
	Livelihood resource vulnerability assessment		X						
	Livelihood asset assessment		X						
	Vulnerability and capacity matrix	X	X						X
	Venn diagram	x			X			X	X
	Effectiveness of coping and adaptation strategies		X					X	
	Communication maps		X	x					
	Reference ranking				X				
	Wealth ranking				X				
Present vulnerability	Brainstorming					X			
	Checklist/multiple attributes					X	X	X	
	Expert judgment					X			
	Focus groups					X	X	X	X
	Indicators/mapping					X			
	Influence diagrams/ mapping tools*					X			
	Stakeholder consultation					X	X		X
	Vulnerability profiles					X		X	
	Ranking/dominance analysis/pair-wise comparison					X			

ADPC=Asian Disaster Preparedness Center, APF=Adaptation Policy Framework, IIED=International Institute for Environment and Development, LFP=Livelihoods and Forestry Programme, SLF=Sustainable Livelihoods Framework

*Note: Christian Aid's version uses Power Structure Analysis.

A2.7 Practical Guidance Tools for Data Collection and Analysis Processes for V&A Assessments

Key concepts	Practical guidance on toolkits suggested for participatory V&A assessment	Local concerns and knowledge associated with past, present and future	Output
Exposure is what is at risk from climate change such as population, resources, property and the change in climate itself such as sea level rise, higher temperatures, variable precipitation, and extreme events	Climate change perceptions	Community perception of climate change including the drivers and consequences of climate variability and change	Narrative of varying views on the dynamics of climate change phenomena for further discussion, debate and comparison with available scientific data
	Seasonal calendar, historical timelines, rain calendar, climate diaries and variability	- Climate variability, rainfall patterns, apparent temperature (how hot it feels) - Frequency of extreme climate or weather conditions and events including severe storms, floods and droughts	- Diagram of rainfall and frequency of extreme climatic events - Current causes of extreme climatic events
Sensitivity is the biophysical effects (i.e. flooding, strong winds, land inundation)of climate change which also considers the socioeconomic context of the system being assessed	Hazard mapping, hazard trend analysis, hazard ranking, hazard impact ranking, mental models, transect walk for risk identification, climate impact hazards on livelihood/ vulnerability exposure matrix, participatory scenario development for potential risks	- Climate-related events that have affected the area in the past, either positively or negatively, as a basis for understanding current vulnerability - Degree and range of impacts of different climate hazards on resources, livelihoods and social groups - Poverty, malnutrition, food production, water supply, health, ecosystem loss - Change in seasons, planting and cropping times, native flora and its various uses, and farming and fishing skills and techniques	- Timelines and a table describing past events/ disturbances at the site, consequences and coping strategies - Picture showing the main climatic hazards affecting the project site and who/what is affected , and to what degree of severity - List of vulnerable and social groups
Adaptive Capacity is the ability of a system to adjust to climate change including climate variability and extremes to moderate potential damages, to take advantage of opportunities, or to cope with the consequences, or a function of wealth, technology, institutions, information, infrastructure, "social capital"	Community resources/assets mapping, livelihood resource vulnerability and capacity, livelihood asset assessment, vulnerability and capacity matrix, Venn diagram, adaptation strategies assessment, communication maps, reference ranking, wealth ranking	- Community/household/individual stock of human, social, natural, physical, financial and institutional assets and coping strategies - Land tenure, resource allocation and management, use and benefits obtained from the resources, and relationships between the different resources - Various skills and assets in the community/stakeholder group/ project site - Income level, education, settlement patterns, infrastructure, technology (farming practices), ecosystem and human health, gender, political participation and individual behaviour and social networks	- Map of the study area, available resources and their geographical distribution, and identification of key factors that shape the relationships between the communities - A graphic overview of available capacities, skills and assets (e.g. community wells, boreholes, toilets and septic systems (for flush and water seal toilets), old water reservoirs, cooking and food storage units, generators, land holding units and planting sites, livestock sites, coastal erosion and protection initiatives, village primary schools) - Social actors and biophysical resources
	Participatory scenario building	Community members plan for the future and make adaptation decisions based on their past experiences, current capacity and available assets, and the vision and goals they have for the future	Community members plan for the future and make adaptation decisions based on their past experiences, current capacity and available assets, and the vision and goals they have for the future

With the PVA methods and tools, the local community are empowered to systematically analyse their own problems, suggest their own context-specific solutions and how to achieve those solutions in action planning, project or programme design, implementation, or to serve as baseline data for monitoring and evaluation purposes. The PVA assessment frameworks have attempted to conceptualise climate change and the vulnerability of people to its impacts in compliance with IPCC's definition as a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity. However, the IPCC and adapted PVA approaches do not present vulnerability in terms of an equation. Most participatory vulnerability assessment frameworks try to avoid the mathematical modelling and quantitative generalisations of community vulnerability factors.

A2.8 Comparison of Climate Change V&A Assessment Parameters Adopted by Different Organisations

Framework	Organisation	Vulnerability	Exposure				Sensitivity				Adaptive Capacity			
		Vulnerability as a function of exposure to change, sensitivity to impacts, and ability to adapt	Climate change trends (seasonal)	Climate induced events	Climate projections	Community-based and scientific data	Current hazard trends	Biophysical impacts	Livelihood impacts	Hazard prioritisation	Coping strategies	Livelihood assets	Building community awareness, knowledge and information on CC	Capacity to plan and affect change
Note: Methodologies and framework for assessments: 1=specific and strategic component of the framework; 0=unspecific, implied, or potential component of the framework; empty = not included or addressed in the framework														
Social Adaptation to Climate Change	IUCN	1	0	1	1	1	1	1	1	1	1	1	1	1
Climate Vulnerability and Capacity Analysis	CARE International	1	1	1	1	1	1	1	1	1	1	1	0	1
Community Vulnerability and Adaptation Assessment and Action	SPREP and CIDA	1	1	1	1	1	1						1	
Adoption Toolkit	SEI	1	1	1	1	0	1	1	1	1	1	1	1	1
Participatory Tools and Techniques for Assessing Climate Change Impacts and Exploring Adaptation Options	UKaid and LFP		0	1	0	1	1	1	1	1	1	1	0	0
Participatory Disaster Risk Assessment, step 4 in Community-based Disaster Risk Management	ADPC	1	1	1	0	0	1	0	1	1	0	0	1	1
Participatory Capacity and Vulnerability Assessment	Oxfam Great Britain	1	1	1		0	1	0	1	1	1	1	1	1
Community-Based Adaptation to Climate Change	IIED	1	1	1	1	1	1	1	1	1	1	1	1	1
Adaptation Toolkit: Integrate Adaptation to Climate Change into Secure Livelihoods	Christian Aid	1	1	1	1	1	1	1	1	1	1	1	0	
Mainstreaming Adaptation to Climate Change in Agricultural and Natural Resources Management Projects	World Bank	1	1	0		1	1						1	

ADPC=Asian Disaster Preparedness Center, IIED=International Institute for Environment and Development, IUCN=International Union for Conservation of Nature, LFP=Livelihoods and Forestry Programme, SEI=Stockholm Environment Institute, SPREP-CIDA=Secretariat of the Pacific Regional Environment Programme-Canadian International Development Agency. Source: www.iisd.org/pdf/2012/cristal_user_manual_v5_2012.pdf

Appendix 3: Potential Proxies for National-level Vulnerability to Climate Change Proposed by Adger et al. (2004: 81)

Indicator	Variable	Proxy	Source
Economic well-being (EC)	National wealth	GDP per capita (USD PPP)	WB
	Inequality	GINI coefficient	WIID
	Economic autonomy	Debt repayments (% GNI, averaged over decadal periods)	WB
	National wealth	GNI (total, PPP)	WB
Health and nutrition (HN)	State support for health	Health expenditure per capita (USD PPP)	HDI
	State support for health	Public health expenditure (% of GDP)	HDI
	Burden of ill health	Disability adjusted life expectancy	WHO
	General health	Life expectancy at birth	HDI
	Healthcare availability	Maternal mortality per 100 thousand	HDI
	Removal of economically active population	AIDS/HIV infection (% of adults)	HDI
	Nutritional status	Calorie intake per capita	GRID
	General food availability	Food production index (annual change averaged over 1981-90 and 1991-99)	WB
	Access to nutrition	Food price index (annual change averaged over 1981-90 and 1991-99)	WB
Education (EDU)	Educational commitment	Education expenditure as % of GNP	HDI
	Educational commitment	Education expenditure as % of government expenditure	HDI
	Entitlement to information	Literacy rate (% of population over 15)	HDI
	Entitlement to information	Literacy rate (% of 15-24 year olds)	HDI
	Entitlement to information	Literacy ratio (female to male)	HDI
Physical infrastructure (INF)	Isolation of rural communities	Roads (km, scaled by land area with 99% of population)	WB
	Commitment to rural communities	Rural population without access to safe water (%)	HDI
	Quality of basic infrastructure	Population with access to sanitation (%)	HDI
Institutions, governance, conflict and "social capital" (GOV)	Priorities other than adaptation	Internal refugees (1000s) scale by population	WB
	Effectiveness of policies	Control of corruption	KKZ
	Ability to deliver services	Government effectiveness	KKZ
	Willingness to invest in adaptation	Political stability	KKZ
	Barriers to adaptation	Regulatory quality	KKZ
	Willingness to invest in adaptation	Rule of law	KKZ
	Participatory decision-making	Voice and accountability	KKZ

	Influence on political process	Civil liberties	FH
	Influence on political process	Political rights	FH
Geographical and demographic factors (GDEM)	Coastal risk	km of coastline (scale by land area)	GRID
	Coastal risk	Population within 100km of coastline (%)	GRID
	Infrastructure/disease	Population density	CIESIN
Dependence on agriculture (AG)	Dependence on agriculture	Agricultural employees (% of total population)	WB
	Dependence on agriculture	Rural population (% of total)	WB
	Dependence on agriculture	Agricultural employees (% of male population)	WB
	Dependence on agriculture	Agricultural employees (% of female population)	WB
	Agricultural self sufficiency	Agricultural production index (1985, 1995)	WB
Natural resources and ecosystems (ECO)	Environmental stress	Protected land area (%)	GRID
	Environmental stress	Forest change rate (% per year)	GRID
	Environmental stress	Percent forest cover	GRID
	Environmental stress	Unpopulated land area	CIESIN
	Sustainability of water resources	Groundwater recharge per capita	GRID
	Sustainability of water resources	Water resources per capita	GRID
Technical capacity (TECH)	Commitment to and resources for research	R&D investment (% GNP)	WB
	Capacity to undertake research and understand issues	Scientists and engineers in R&D per million population	WB

Sources: World Bank World Development Indicators 2012; UNDP Human Development Index (HDI); United Nations Environmental Programme/Global Resource Information Database (UNEP/GRID); Kaufmann, Kray and Zoido-Lobaton (KKZ) governance dataset; Centre for International Earth Sciences Information Network (CIESIN); UNU-WIDER World Income Inequality Database (WIID).

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