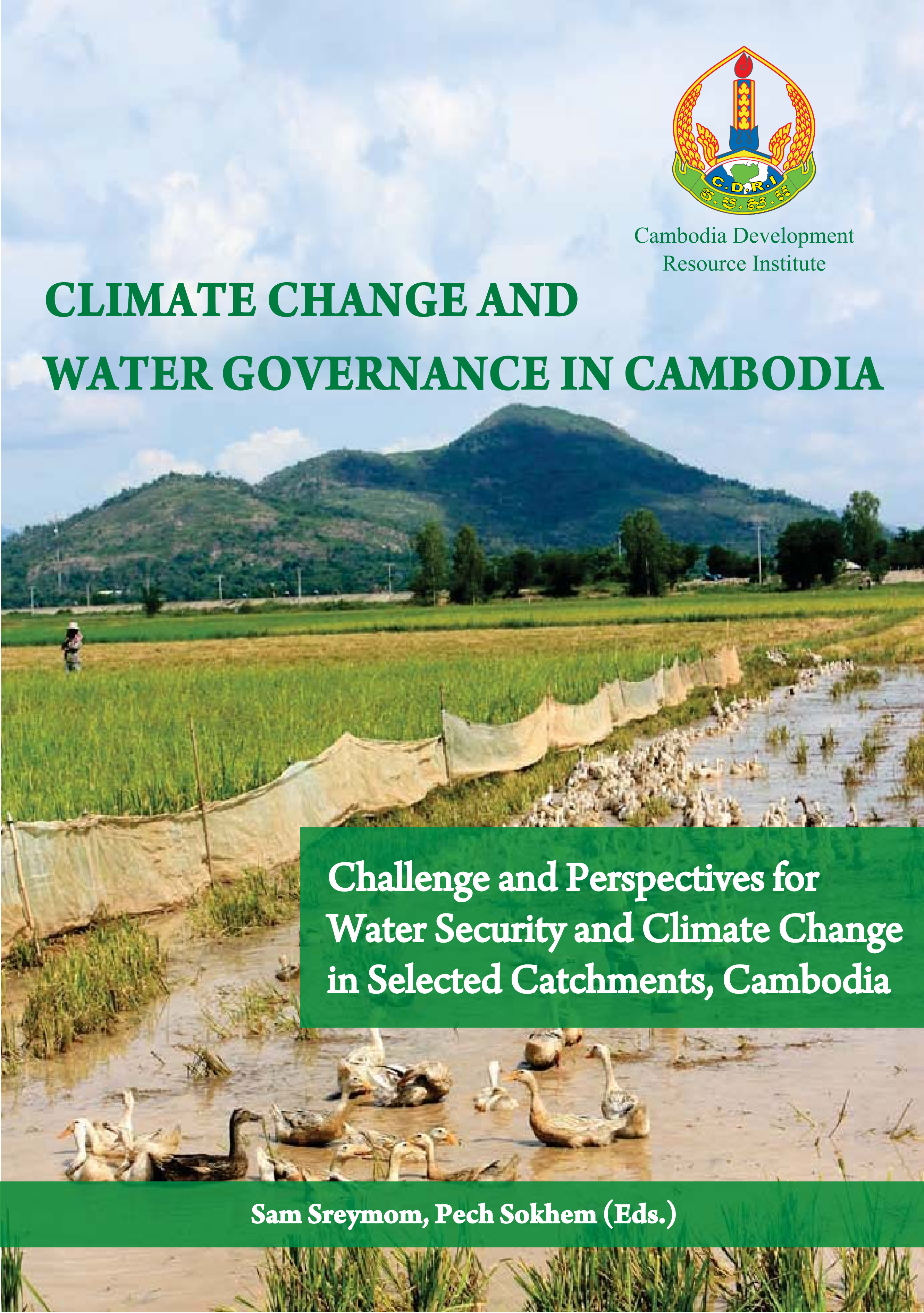

Cambodia Development Resource Institute

CLIMATE CHANGE AND WATER GOVERNANCE IN CAMBODIA

Challenge and Perspectives for Water Security and Climate Change in Selected Catchments, Cambodia

Sam Sreymom, Pech Sokhem (Eds.)

CLIMATE CHANGE AND WATER GOVERNANCE IN CAMBODIA

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Edited by

Sam Sreymom, Pech Sokhem

Cambodia Development Resource Institute

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Preface

This book is the major output of a three-year research project titled "Climate Change and Water Governance in Cambodia", supported by the International Development Research Centre (IDRC) of Canada. The book is the result of close collaboration between the Cambodia Development Resource Institute (CDRI), a lead institute, and project partners: the Ministry of Water Resources and Meteorology (MOWRAM), Ministry of Environment (MOE), Tonle Sap Authority (TSA), Royal University of Agriculture (RUA), Institute of Technology of Cambodia (ITC) and the Mekong Programme on Water, Environment and Resilience (M-POWER).

The project focussed on three river catchments around the Tonle Sap Lake: Stung Chrey Bak in Kompong Chhnang province, Stung Chinit in Kompong Thom province and Stung Pursat in Pursat province. The main research outcomes encompass (1) better understanding among decision makers, researchers and students of the livelihood implications of hydrological and ecosystem changes caused by changes in climate and human systems in the Tonle Sap Basin, and (2) improved methods of integrating local knowledge and scientific empirical evidence into Cambodia's policy and planning framework.

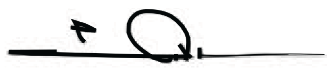
This comprehensive assessment of issues concerning water governance, climate change and adaptive capacities in three provinces confirms that changes in the climate are affecting local community livelihoods, though effects vary depending on location. The shift in the arrival of wet season rains clearly has implications for both wet and dry season farming. Importantly, the study highlights the problems that matter most to local communities, particularly increases in the frequency of floods and lightning storms, and which they view as part of their vulnerability to climate change.

Adaptation planning for climate change requires coordinated and informed decisions and a framework for mainstreaming climate resilience into development planning. CDRI and its partners are pleased to have contributed to the improvement of science-based planning for climate change adaptation and water resources management in the Tonle Sap Basin. The knowledge products generated by this project will help improve the understanding of decision makers at local and national levels about (1) how changes in climate and human systems affect water availability and water security; (2) the implications of changes in water availability for livelihoods in the study catchments; and (3) how positive effects of climate change and improved water governance can increase adaptive capacity and achieve water security.

We are delighted that key stakeholders who participated in the series of provincial and national workshops and training courses have approved the key findings and recommendations. On behalf of the Co-Chair of the Project Steering Committee, we would like express our deep gratitude to all stakeholders for their support and cooperation in developing this project. We are also grateful to line ministries and government institutions, development partners, Cambodian civil society, the private sector and academia for contributing to the development of this project and this book.

Phnom Penh
December 2015

Dr Chhem Rethy
Executive Director, CDRI



HE Ponch Sachak
Director General, MOWRAM

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We extend our deep gratitude to the International Development Research Centre (IDRC) of Canada, and the Canadian government, for the vital funding and technical support provided to the Climate Change and Water Program under IDRC's Research Initiative on Water Resources and Adaptation to Climate Change in Asia. We would like to acknowledge IDRC project staff for their contribution to the project's success, especially the academic expertise, generous support and continuous guidance of Dr Charlotte MacAlister and Dr Sara Ahmed.

Many people and organisations, too numerous to mention individually, contributed their valuable inputs and ideas throughout the research process, in drafting the initial findings and recommendations and in reviewing the final report. Our appreciation also extends to all participants in project-related events, including national and provincial workshops, for their feedback and comments on the manuscript.

Farmers, water-user community leaders, provincial department officers, commune councillors and village leaders were particularly helpful in sharing their local knowledge and insights. We are grateful to them for their active involvement in the project.

We acknowledge with sincere thanks the many national and international specialists who provided useful and practical suggestions.

Abbreviations and Acronyms

APN	Asia-Pacific Network
CBO	community-based organisation
CCCSP	Cambodia Climate Change Strategic Plan
CCDM	Commune Committee for Disaster Management
CDP	Commune Development Plan
CDRI	Cambodia Development Resource Institute
CIP	Commune Investment Plan
CISIS	Cambodia Irrigation Scheme Information System
CSF	Commune/Sangkat Fund
CSO	civil society organisation
D&D	decentralisation and deconcentration
DHRW	Department of Hydrology and River Works
DWRM	Department of Water Resources and Meteorology
ETo	evapotranspiration
FGD	focus group discussion
FWUC	farmer water user community
IDRC	International Development Research Centre of Canada
IPCC	Intergovernmental Panel on Climate Change
ISF	irrigation service fee
ITC	Institute of Technology of Cambodia
IWR	irrigation water requirement
IWRM	integrated water resources management
KII	key informant interview
m^3	cubic metre
M&E	monitoring and evaluation
MAFF	Ministry of Agriculture, Forestry and Fisheries
masl	metres above sea level
MCM	million cubic metres
MOE	Ministry of Environment
MOI	Ministry of Interior
MOWRAM	Ministry of Water Resources and Meteorology
M-POWER	Mekong Programme on Water, Environment and Resilience
MRC	Mekong River Commission
MRD	Ministry of Rural Development
NCDD	National Committee for Sub-National Democratic Development
NCDM	National Committee for Disaster Management
NCSD	National Council on Sustainable Development
NGO	non-governmental organisation
NSDP	National Strategic Development Plan
PDMC	Provincial Disaster Management Committee
PDWRAM	Provincial Department of Water Resources and Meteorology
RUA	Royal University of Agriculture
SRES	Special Report on Emissions Scenarios
TSA	Tonle Sap Authority
UNDP	United Nations Development Programme
URBS	Unified River Basin Simulator
V&A	vulnerability and adaptation
VDMG	Village Disaster Management Group

Chapter 1
Why the Focus on Water Governance and Security?

Pech Sokhem, Chem Phalla, Sam Sreymom

1.1 Background

Throughout history, rivers have been the places where civilizations were established and people have prospered. A Chinese historian and envoy—Zhou Daguon, writing in the late 13th century—put the success of the Khmer Empire down to Angkor's remarkable water engineering and extensive irrigation and drainage system (Asienreisender 2013; Dumarçay and Royère 2011). From the 9th to 15th centuries the "hydraulic city" of Angkor served as the seat of the Khmer Empire and became the most extensive urban complex of the preindustrial world (Aphisit 2011).

Many studies have identified that surface water and groundwater interaction play an important role in ensuring not only water and food security but also the structural stability of Angkor's temples—an invaluable cultural heritage (Evans et al. 2007; Kummu 2009; Buckley et al. 2010). Research further confirms that the downfall of the Khmer Empire was caused by ecological imbalance and infrastructure breakdown due to severe droughts and floods, drastic changes in land cover and poor maintenance of hydraulic systems. The then leaders and rulers either did not recognise the risks until it was too late or could not prevent progressive collapse (Asienreisender 2013; Earth Institute 2013). It is hoped that history does not repeat itself in this amazing country.

Building resilience to climate variability, recognising climate-sensitive linkages between sectors and promoting sustainable development and integrated climate risk management require policies and plans that are informed by scientific evidence (Walker et al. 2004). Despite progress in assessing and projecting climate change impacts, vulnerability and adaptation studies in Cambodia provide an insufficient understanding of existing vulnerabilities, thereby constraining adaptation and mitigation responses. This is particularly the case at subnational levels. Given the high spatial variability of climate impacts and vulnerabilities, developing a comprehensive understanding of site- and context-specific vulnerabilities is essential for determining the best adaptation responses and building climate resilience (MOE 2013).

This book grew from a three-year project titled "Climate Change and Water Governance in Cambodia". The aim of the project was to gain and share better understanding of how interactions between changes in natural systems and human systems affect water security in the catchments, and what bearing these effects have on the vulnerability and adaptive capacity of local communities. The objective was to suggest adaptation actions and responses to address the potential consequences of climate change impacts.

The results of the study have significantly deepened our understanding of the nature and hazards of vulnerability. This understanding is pivotal for building community and household resilience to current and projected risks in constantly changing contexts. As such, it contributes to the improvement of science-based planning for climate change adaptation and water resources management in selected catchments of the Tonle Sap Basin.

1.2 Setting the context

The Cambodian government has reiterated that climate change is one of the most important problems confronting policymakers around the world, including in Cambodia, and which continues to shape international, national and subnational development agenda (MOE 2015). In 2012, Cambodia was ranked 28th in the 2nd Global Risk Index 2013. Up to 80 percent of the country's population live in rural areas, and about 75 percent remain below or marginally above the poverty line (USD1.25 per person per day), leaving them vulnerable to economic, social and environmental shocks. Even the smallest shock can send this population group spiralling into poverty (MOE and UNDP 2011).

Water is essential for meeting basic human needs. It is the single most important component for sustainable rice production, which is the basis of food security and main source of rural livelihoods in Cambodia (MOWRAM 2014). The concept of water security brings to the fore an interdisciplinary, integrative approach to water management that spans physical and social sciences such as agronomy, engineering, environmental sciences, social and political sciences and hydrology (Cook and Bakker 2012). Supplying enough water to meet the growing demands of agriculture, sanitation, industry and urbanisation involves engineering to develop water infrastructure as well as soft interventions and safeguards such as water resources planning and management. Regulating water quantity and quality to sustain ecological and environmental functions and maintain ecosystem services for human and economic needs entails environmental science (UNDP 2013).

Water security problems are common in the Tonle Sap Basin, particularly in the study catchments. And they are expected to intensify due to heightened economic activity including major infrastructure development, current climate variability and future climate change. Increases in the magnitude and frequency of floods and droughts coupled with further changes in both natural and social systems will render populations and communities vulnerable in multiple ways (MOE 2013).

Vulnerability to current climate hazards and future climate change is determined by exposure to risk, the degree to which human and ecological systems are sensitive to hazards and their capacities to adapt to these shocks and changes (IPCC 2007). Cambodia is highly vulnerable to both climate variability and climate change because of its low capacity to adapt and its heavy reliance on climate-sensitive sectors such as water resources and agriculture (paddy rice, crops, fisheries and forestry) (MOE 2002; RGC 2013; MOE 2015; MOE and UNDP 2011; CamboWP 2015). Livelihood activities and economic sectors dependent on these resources have traditionally been highly sensitive due to the country's unique geographic conditions and hydrological system. Moreover a lack of proper mainstreaming of climate resilience measures into national development and planning makes existing problems worse (Eastham et al. 2008).

The latest National Water Status Report (MOWRAM 2014) confirms that the frequency and intensity of floods, droughts and windstorms has increased since 1989, when national weather and climate data began to be reliably recorded (MOWRAM 2014). Abnormal variations in river flows, water levels and rainfall patterns have significant impacts on the hydrological regime, and can ultimately undermine the availability and stability of water resources critical for economic growth, livelihoods and well-being. Water insecurity clearly poses huge challenges to Cambodia's ability to achieve the Millennium Development Goals and future Sustainable Development Goals (RGC 2012; MOWRAM 2014).

As shown in Box 1.1, disasters and climate hazards have exacted huge socioeconomic costs on the country. The 2000, 2011, 2002 and 2013 floods were among the worst disasters in recent history, resulting in a high number of internally displaced people, hundreds of deaths and other losses (NCDM 2013). Severe widespread flooding in 2011 destroyed much of the last 10 years of investment in rural infrastructure on the Mekong and Tonle Sap floodplains. About 360 km of national and provincial roads and 4469 km of rural roads were damaged (out of a total of 12,263 km of primary and secondary roads) (RGC 2012, 2013).

The Tonle Sap Basin is undergoing worrying hydrological change, as confirmed by the AusAID-funded "Exploring Tonle Sap Futures" study (Keskinen et al. 2011). The study stresses that changes in the Tonle Sap flood pulse and water regime over the next 30 years are more likely to be caused by infrastructure developments than by climate change. But climate change will compound these water challenges and cause further uncertainties.

Box 1.1: Damage and deaths caused by recent climate disasters

- Flooding in 2013 caused significant economic damage estimated at USD700 million to USD750 million, the equivalent of 37 percent of entire national spending (USD2 billion) in 2011, and affected 1.7 million people in 20 of 24 provinces and municipalities.
- Floods in 2011 affected 354,217 households (more than 1.7 million people) in 18 provinces, and costs in terms of lost assets amounted to between USD521 million and USD624 million.
- Typhoon Ketsana in 2009 affected 14 out of 24 provinces and cost the Cambodian economy USD132 million in yield and production losses and infrastructure damage.
- Severe floods in 2000-02 caused 438 deaths and about USD205 million worth of damage.

Sources: MOE 2014; NCDM 2014

Unless issues pertaining to water security and climate resilience are properly addressed, it will be difficult to achieve food and energy security, environmental sustainability, poverty alleviation and other key development goals as set out in Rectangular Strategy Phase III 2014-18 (RGC 2013). Effective strategies and action plans to deal with these challenges will require accurate and reliable water resources assessment (MOE 2013).

Improving water security by ensuring timely access to sufficient water, managing physical and economic water scarcity and mainstreaming climate resilience into national and local development planning are critically important in helping communities cope with and recover from the impacts of current and future threats (MOE 2014; MOE and UNDP 2011).

1.3 Selection of study sites

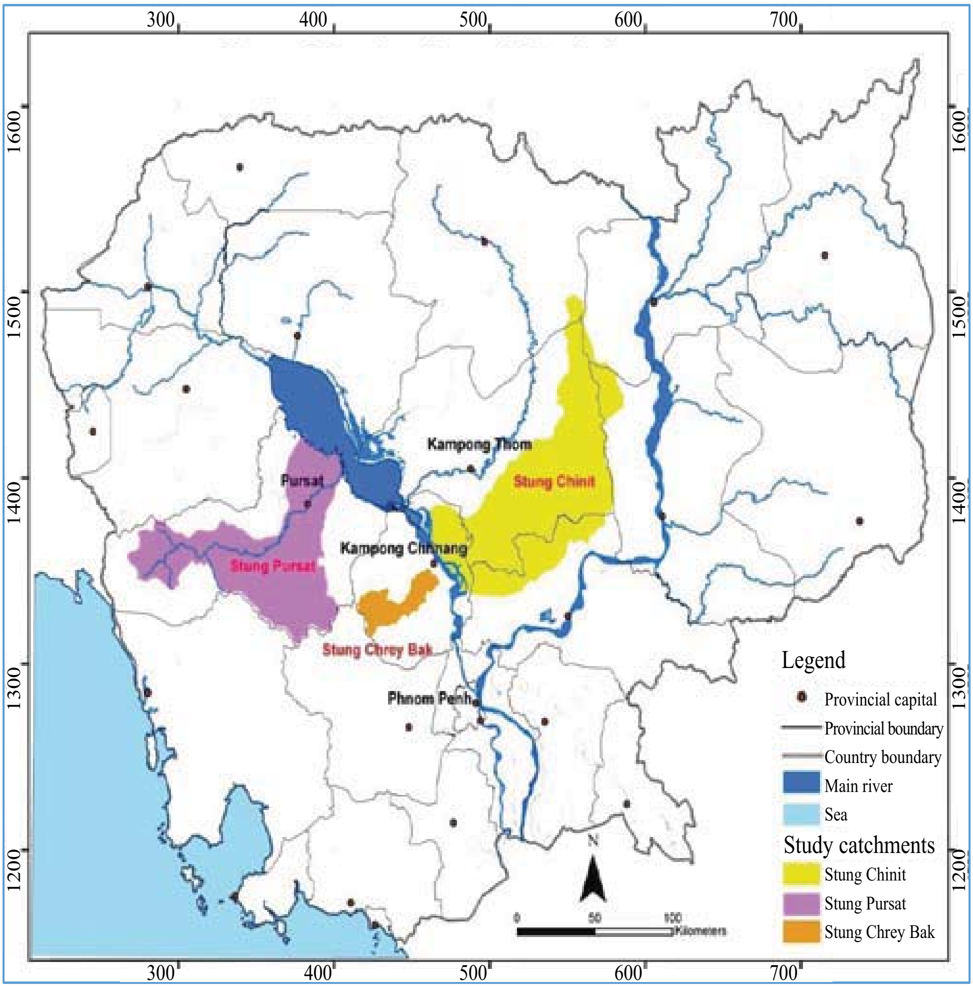
Of the 12 catchments surrounding the Tonle Sap Lake, three were selected for study:

- Stung Chrey Bak catchment in Kompong Chhnang province forms part of Stung Baribour catchment and covers an area of about 790 km^2.
- Stung Pursat catchment in Pursat province covers an area of about 5964 km^2. The main stream feeds many large, medium and small-scale irrigation schemes in the catchment and, through interbasin diversion schemes, also supplies neighbouring catchments before draining into the Tonle Sap Lake.

- Stung Chinit catchment in Kompong Thom province covers an area of about 8236 km^2. The main stream flows 264 km southwestwards to the gentler slopes downstream from the Tonle Sap Lake (CNMC 2012).

All three catchments represent diversity in terms of catchment scale, upstream-downstream water conflicts, and vulnerability. Sharing of water among competing water users and between upstream and downstream farmers is complex, and there are significant interactions between different types of water uses. Farmers endure an endless barrage of abnormal storms, floods and multiple kinds of droughts (meteorological, hydrological and agricultural), making them and their communities highly vulnerable to water scarcity. The catchments are also experiencing intensified economic activity including major land concessions, infrastructure developments and demographic pressures (CNMC 2012).

Figure 1.1: Location of study sites



Source: Chem and Kim 2013

1.4 Structure of the book

The book synthesises a large volume of data and findings collected from a comprehensive literature review, a series of empirical studies, and participatory research activities at local, subnational and national levels. Following this introduction, the book is divided into three main parts. Part 1 presents three case studies on water resources and water security under climate change in three subcatchments of the Tonle Sap Basin. These are complemented in Part 2 by a participatory assessment of key elements of vulnerability. In Part 3, the empirical and theoretical literature review in Chapter 6 describes how climate change adaptation and water governance can enable resilient local social-ecological systems, while Chapter 7 focuses on adaptive governance for water security and climate resilience. Chapter 8 concludes the vulnerability and adaptation assessment and suggests ways forward to reduce vulnerabilities, improve adaptation and build resilience.

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PART 1

Assessment of Water Resources and Water Security under Climate Change in Three Catchments

PART 1
Assessment of Water Resources and Water Security under Climate Change in Three Catchments

Background to case studies

Cambodia has abundant water resources but they are spatially and temporally unevenly distributed. In reality, many communities, including in the study sites of Stung Chinit, Stung Chhrey Bak and Stung Pursat, face problems brought on by too much or too little water. This situation is compounded by the effects of catchment degradation caused by physical alteration of inland water systems (both quantity and quality), deforestation and habitat destruction, water withdrawal for agriculture, mining and urbanisation, pollution, and hydrological and environmental changes due to infrastructure developments within and outside of Cambodia (MOWRAM and MOE 2013).

A primary objective of our research is to provide a better understanding of present and future climate conditions and trends in water resource availability in three subcatchments of the Tonle Sap Basin, by:

- assessing the impacts of changes in natural and human systems on water security: how and to what extent these changes affect water security in catchment areas;
- sharing the key findings from the hydrological change assessment and publicising the consequences for ecosystems and livelihoods in the selected catchments; and
- suggesting practical recommendations for integrated national, subnational and community action plans and policy, and future research directions.

Three case studies, described in Chapters 2-4, were conducted to assess climate change impacts such as changes in temperature, frequency and intensity of floods and droughts, and agricultural conditions over time and across topographical zones. A vulnerability and adaptation assessment, portrayed in Chapter 5, builds on the findings of these case studies. The resulting synthesis of quantitative analysis of exposure to climate risks and ecological sensitivity and qualitative analysis of adaptive capacities (social, economic, political, physical and natural) is presented in Chapter 8.

Approaches and methodology

The methods used were designed to ensure the rigour and credibility of the research. Information on the physical features of the catchment, and observed and forecast hydrometeorological data, were carefully gathered. Rigorous analysis involved the set up and calibration of a hydrologic model, water balance estimation, and baseline and climate change simulation. Constructive feedback was sought from participants at both provincial and national validation workshops and consultation meetings. Organised at provincial level in three provinces, workshops and meetings also aimed to raise awareness of key issues, share local information and highlight potential adaptation strategies.

The study team developed and applied water resource models to support analysis of integrated water resources management. Key research questions and processes were identified. A knowledge-based problem-solving platform was created by combining the best available information, models and approaches and collecting additional data to fill local knowledge gaps.

The assessment built on previous research findings and science-based information including literature on irrigation, ground and surface water flows, downscaling of climate change projections, and water resources management; hydrological data collected in the river catchment; downscaled climate data from ECHAM4;[1] and mini-studies of water resource development in the study catchments.

Data was gathered on agricultural and irrigation planning, flood protection and management, reservoir capacity design, hydropower planning, road design and drainage planning. Accurate quantitative data on rainfall distribution, rain intensity and length of dry periods was compiled for climate change downscaling. The collected data was input into the hydrological models to simulate projected run-off and river water discharge based on historical statistical data and future climate change scenarios. Particular attention was paid to extreme events such as flood and drought.

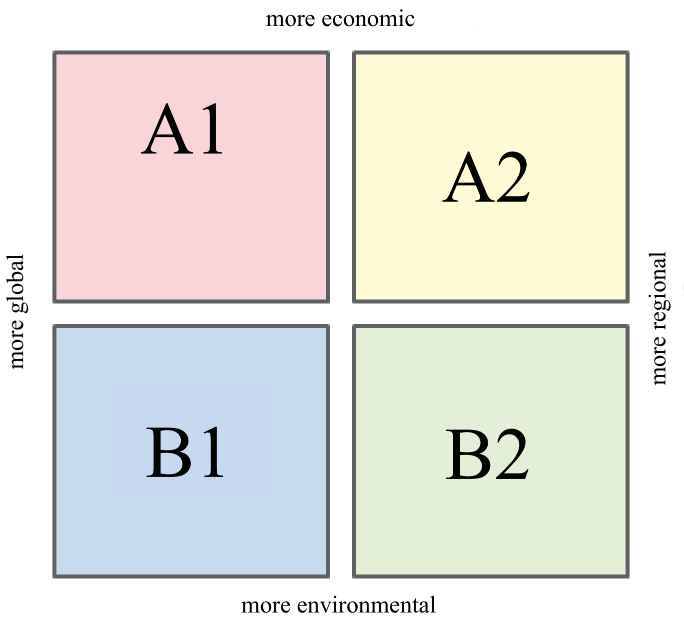
Two modelling approaches were used to describe the water balance status and amount of water available for allocation under current and forecast conditions.

1 ECHAM4 is the current generation in the line of ECHAM models developed for climate simulations. The model is a spectral transform model with 19 atmospheric layers, and the results used here derive from experiments performed with spatial resolution T42 (which approximates to about 2.8º longitude/latitude resolution) (Roeckner et al. 1992).

Rainfall-runoff models estimate flows for intake diversion by means of a computerised river catchment model. URBS (Unified River Basin Simulation) model was used in Stung Chinit, ArcSWAT (soil and water assessment tool) in Stung Pursat and Stung Chhrey Bak.

Water balance models estimate water availability against water use using WEAP (water evaluation and planning) and CroPWat decision-support tools to calculate crop water requirements and irrigation requirements for Stung Chhrey Bak, IQQM (integrated quantity and quality model)river basin simulation for Stung Pursat, and a simplified water balance model in Excel for Stung Chinit. Crop water requirements were estimated by computing evapotranspiration (ETo) and by confirming water resources security in the river basin and proposing areas for new irrigation projects.

Climate change scenarios for the Tonle Sap Basin were obtained from the Special Report on Emissions Scenarios (SRES) (IPCC 2000). There are 40 scenarios, each making different assumptions about future emissions and outcomes. The study selected four scenarios, as detailed below; each case study examined one or two of these scenarios.



Source: Special Report on Emissions Scenarios (IPCC 2000)

- A1 is based on a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter and the rapid introduction of new and more efficient technologies.

- A2 represents a business-as-usual scenario, with a very heterogeneous world, fragmented development and continuously increasing population.
- B1 represents a balance across all sources, where balance is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies.
- B2 represents a world with population increasing at a rate lower than A2, and with intermediate levels of economic development.

The models were run for each scenario to evaluate future climatic conditions, specifically changes in rainfall, water availability and dry extremes. Because of errors, biases and uncertainties in the raw climate projection data, particular attention was paid to understanding local climate processes and to data correction.

Water balance computation[2] was carried out for a baseline scenario. Climate change scenarios used ECHAM4 climatic data downloaded from SEA START. SEA START's downscaling of ECHAM4 using a PRECIS model for Southeast Asia was set to a resolution of 0.22 degrees, and the output was further rescaled to 20 x 20 km resolution.

The study stressed the importance of distinguishing between climate parameters for mean values and variability, since extreme weather events are often more critical than shifts in mean conditions. Predicting and understanding variability is harder than predicting and understanding mean values (MOE 2013).

Quantitative and qualitative analyses were used to examine (1) the opportunities for, and threats to, sustainable water resource management; and (2) impacts on key water-dependent sectors, such as agriculture.

---

2 The following assumptions were made for computation:

- ➢ A simple reservoir routing was formulated for the schemes where information on reservoir characteristics is available.
- ➢ Return flow from upper scheme was used as part of inflow for downstream scheme, defined as:
  - ✓ 17% of irrigation water requirements (IWR) or 50% of irrigation loss if there is no deficit
  - ✓ 17% of (IWR – deficit) if there is a deficit.
- ➢ Seepage was assumed to be 0.05% of reservoir volume per day.
- ➢ Evaporation from the reservoir uses observed values at Pochentong meteorological station.
- ➢ ETo was computed by the Penmann method using climate components at monitoring stations.

Assumptions, limitations and uncertainties

Climate trends in the Mekong region, not to mention in Cambodia and the study sites, remain poorly understood. Some analyses show conflicting results, and some are inconclusive or carry limited statistical confidence due to insufficient information.

First, the models had to assess what water was or would be available in the catchments, and what the water demand was or would be for irrigation, domestic and industrial purposes and energy generation. The models also had to simulate water demands for instream uses and ecological flow requirements under climate change. However, there was very limited hydrometeorological data to represent characteristics in enough detail within each catchment (MOWRAM and MOE 2013). For example, there was only one operational hydrological station in Stung Chinit catchment, at Kompong Thmar. The station has been operational only since 1997, and does not record flows drained by the Stung Chinit subcatchment. There is another station on the Stung Taing Krasaing at Taing Krasaing, but only water level is observed. There is no hydrological station at either the catchment outlet or the irrigation schemes.

Nonetheless, the models were calibrated to available data so that the end-users have a known level of confidence in their results to an acceptable standard to ensure that volume, seasonal flow distribution, daily flow distribution and daily and monthly flow peaks are measured accurately.

To overcome data limitations, the flow estimation simulations were carried out using a computerised river catchment (rainfall-runoff) model at different points of interest. The model required rainfall data as a minimum input, digital elevation data, and information on river networks.

Second, uncertainties also stem from our incomplete knowledge of the climate system and its representation in climate models. Downscaled data using regional climate model and global climate model datasets is coarse and based on uncertainty in the trajectory of future emissions and concentrations of greenhouse gases and aerosols (MOE 2013). Natural variability inherent in the climate system is another cause of uncertainty.

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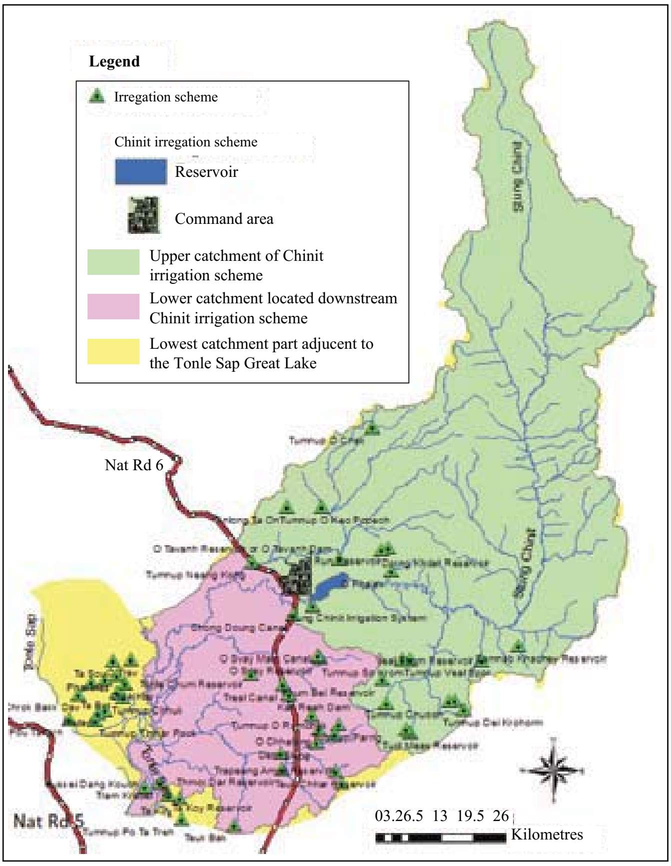
Chapter 2
Stung Chinit Catchment

Tes Sopharith, Pech Sokhem, Chem Phalla

2.1 Physical features of Stung Chinit catchment

There are 50 irrigation schemes in Stung Chinit catchment (Figure 2.1), but the Stung Chinit scheme is the biggest, consisting of a diversion weir and 750 m spillway, a 16-km main canal, five secondary canals and a few well-designed tertiary canals. The main reservoir has storage capacity of 35.6 MCM and storage area of 27 km^2. Most of the canals in the system are gravity-fed. This study specifically considered the impacts of water resources development in the upstream area of the Chinit irrigation system (i.e. the area above National Road 6). Water balance computation was done for 20 schemes, of which 17 are located upstream; these have small reservoirs but are poorly managed and have deteriorated in quality.

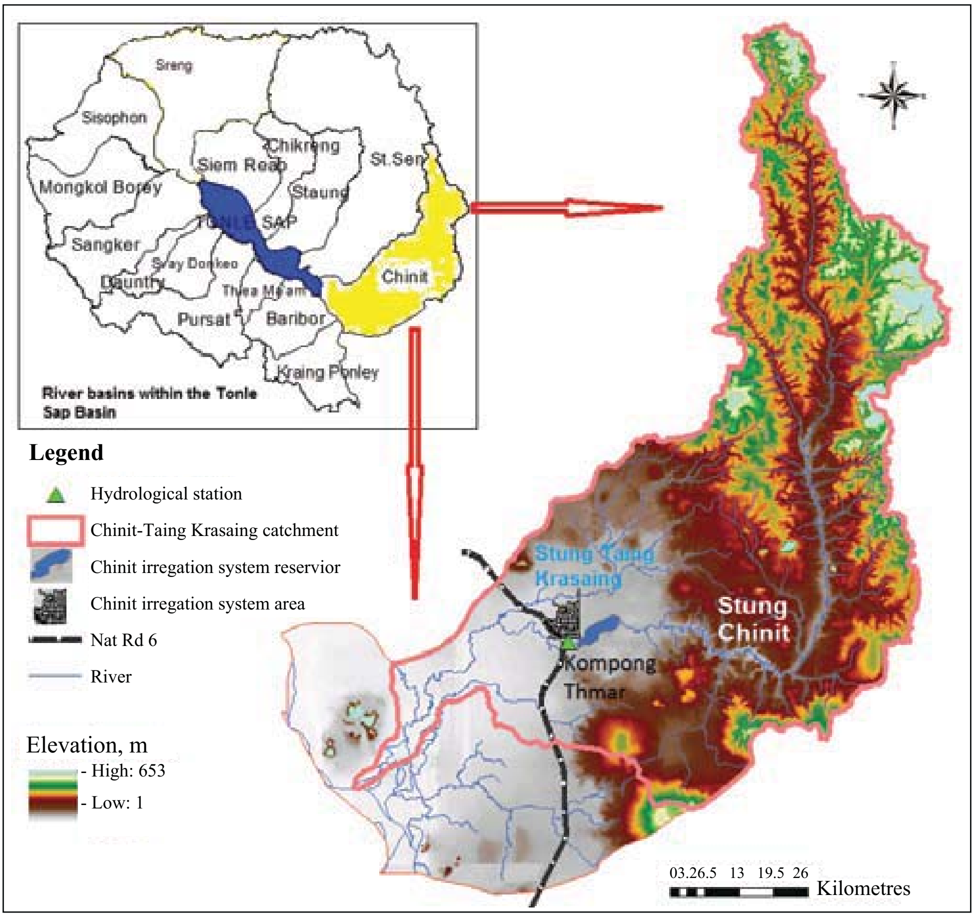
Figure 2.1: Irrigation schemes within Stung Chinit catchment



Source: Cambodia Irrigation Schemes Information System (MOWRAM 2014)

Stung Chinit catchment is composed of the Stung Chinit and Stung Taing Krasaing rivers and other small streams that drain from the north and flow southwestwards for 240 km before discharging into the Tonle Sap Lake (Figure 2.2). The catchment covers an area of 8236 km². The flow of the Chinit River is measured at the only gauging station, located at Kompong Thmar bridge on National Road 6.

Figure 2.2: Location of Stung Chinit catchment, elevation and river network



Source: MRC digital elevation model (DEM) map 2001

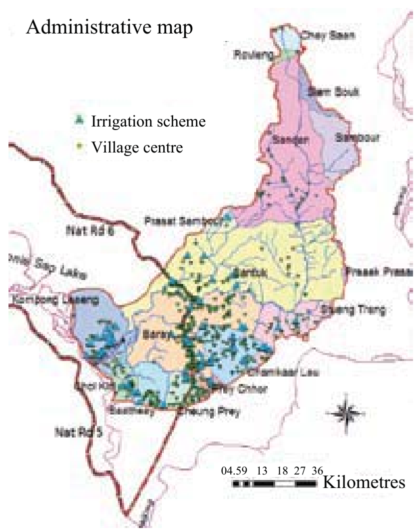
The climate in Stung Chinit catchment mirrors Cambodia's overall climate pattern, dominated by tropical monsoons, with pronounced wet and dry seasons. Rainfall in the catchment increases with elevation. The spatial distribution of annual average rainfall ranges from 1200 to 1500 mm: maximum annual monthly rainfall has been as low as 20 mm in the dry season and up to 530 mm in the wet season, and minimum monthly rainfall has dropped to zero over the dry season and as low as 50 mm during the wet season. Over 90 percent of the catchment's annual rainfall is received during the wet season, from May to October, and the highest rainfall occurs in August. Water is abundant during the wet season, but flows are much lower in the dry season with severe scarcities (MOWRAM 2014).

Daily temperatures vary from a maximum of 35 °C during the hottest months of April and May to 20°C in the coolest months of December-January. The Stung Chinit River is regulated by a weir about 5 km upstream from the gauging station. An area 3-5 km downstream of the Stung Chinit irrigation scheme is inundated to a depth of 1 to 5 m annually by the Tonle Sap flood pulse (CNMC 2012).

The Stung Chinit catchment embraces 16 districts across six provinces and has a total population of 515,183 (NIS 2009), with an average annual population growth rate of 0.2 percent (CNMC 2012). Most people live in the lower part of the catchment and along National Road 6 (Figure 2.3). The farmers of Stung Chinit and Taing Krasaing mainly cultivate traditional wet season rice and some dry season rice; they also fish and raise livestock.

Figure 2.3: Provinces, districts and villages in Stung Chinit catchment

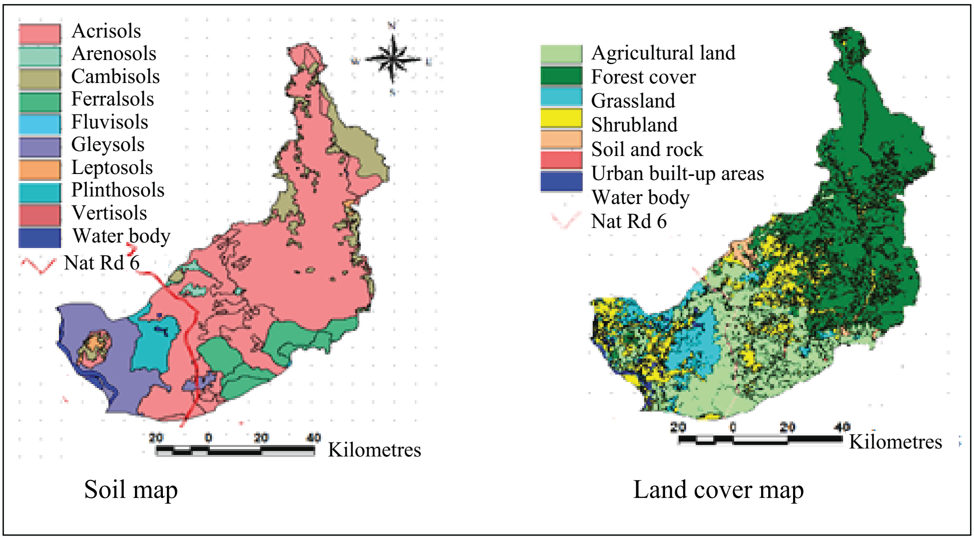
Within Stung Chinit catchment						Use water from Chinit River
Province	District code	District name	# Communes	# Villages	Population (Census 2008)	
Preah Vihear	1301	Chey Saen	1	2	1163	yes
	1305	Rovieng	1	1	528	yes
Stung Treng	1902	Siem Bouk	1			
Kratie	1004	Sambour	2			
	1003	Preaek Prasab	1			
Kompong Cham	0315	Stung Trang	7	35	43134	yes
	0302	Chamkar Leu	8	72	90606	yes, 60%
	0301	Baatheay	4	27	27435	no
	0303	Cheung Prey	8	37	38147	no
	0313	Prey Chor	5	20	16096	no
Kompong Thom	0606	Sandan	5	23	12566	yes
	0605	Prasat Sambour	1	1	509	yes
	0607	Santuk	9	73	62569	yes
	0601	Baray	18	181	167581	yes, 40%
Kompong Chhnang	0404	Kompong Leaeng	9	36	37680	yes
	0402	Chol Kiri	5	14	17169	no
Total		16	85	522	515183	



Sources: MLMUPC 2013; NIS 2009

A large proportion of the catchment has poor quality soils (Figure 2.4 on the left), comprising Acrisols (60.75 percent) and better soil groups such as Gleysols (12.74 percent), Cambisols (10.13 percent), Ferrasols (8.73 percent) and Plinthosols (4 percent). Other soil types and water bodies cover the remaining 4 percent of the total catchment area (CNMC 2012).

Figure 2.4: Soil and land cover for Stung Chinit catchment



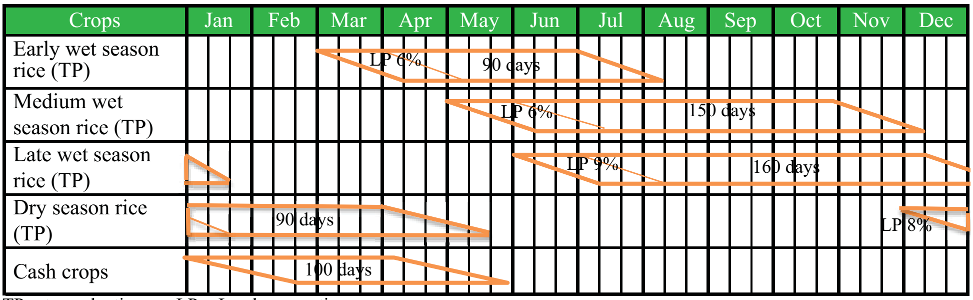
Source: MRC soil and forest cover maps in 2002

Agricultural land occupies 28.9 percent of the total catchment area (238,020 ha), located mostly on poor Acrisols. Another 46.3 percent of the catchment area (381,327 ha) is occupied by forestland, grassland, shrubland, soil and rock, urban settlements and water bodies. Of the total agricultural land, rice takes up 154,014 ha, annual crops 49,197 ha, perennial crops 22,938 ha and village garden crops 7331 ha (CNMC 2012).

The study adopted a 95 percent exceedance probability of monthly base flows as the environmental flow. This value is slightly higher than the lowest annual minimum river flow under natural conditions.

Five different cropping patterns (Figure 2.5) were applied, and it was assumed that all 20 irrigation schemes use those cropping patterns and associated calendars year round: early, medium and late duration varieties of rice in the wet season, early-maturing rice in the dry season and cash crops. Cropping patterns for rice are based on the assumption that transplanting is the dominant farming practice. This method produces a higher unit yield of rice than direct sowing. Irrigation areas for each cropping pattern are based on the information obtained from the Cambodia Irrigation Schemes Information System database (MOWRAM 2014). Water is diverted from the irrigation schemes to meet wet and dry season irrigation demands to support 100 percent and at least 50 percent, respectively, of the total crop area.

Figure 2.5: Cropping patterns and calendars



TP = transplanting LP = Land preparation

Population for any specific year was projected using the 2008 census database. Domestic and industrial water use per capita in Cambodia was determined at 65 litres/day, taking into account that domestic use is 50 litres/day and industrial use is 30 percent of domestic use. This rate is a recommendation of the World Health Organization (MOWRAM 2014).

Water balance was calculated to estimate water excess or deficiency in meeting human and environmental needs (i.e. water consumption versus total water availability at a selected location and time) based on a catchment schematic diagram, reservoir data, generated runoffs (using river basin simulation) and water demands (irrigation, domestic, industrial, environmental flow, return flow and reservoir loss).

The water balance computation was carried out for two scenarios—past (baseline) and future. The baseline scenario used hydrological data from 1992 to 2011 to calculate present domestic and industrial water use in 20 irrigation schemes upstream of National Road 6. For future trends, the model was run for two socioeconomic scenarios, SRES A2[1] and SRES B2[2], for 2020 and 2050 (IPCC 2000).

1 The A2 scenario family describes a very heterogeneous world where the population is continuously increasing, economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines (IPCC 2000).

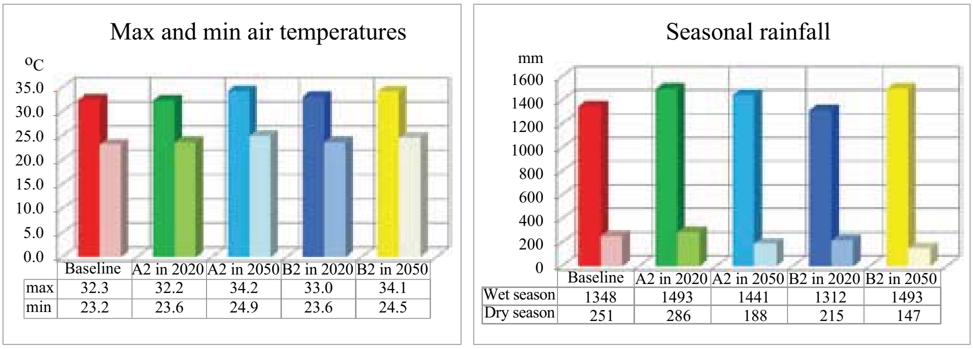
2 The B2 scenario describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability in a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels (IPCC 2000).

2.2 Findings and discussion

2.2.1 Climate change

Based on the dynamic downscaling done by SEA START, the climate in Stung Chinit catchment in 35 years is projected to be warmer, with a longer dry season and heavier rainfall during the wet season. Comparison with the present baseline for air temperature at Kompong Thmar station (Figure 2.6 on the left) indicates a significant rise in maximum temperature of 1.8°C (SRES B2) to 1.9°C (SRES A2) by 2050.

Figure 2.6: Change in maximum and minimum air temperatures and seasonal rainfall at Kompong Thmar station



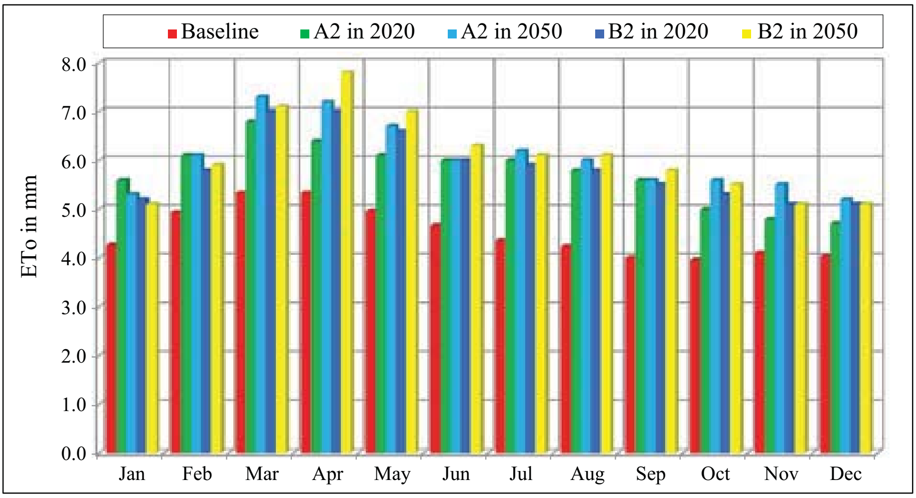
Sources: Raw observed climatic data from Department of Meteorology (unpublished); raw climate change data from SEA START (http://gis.gms-eoc.org/ClimateChange/)

A comparison with the present rainfall baseline conditions at Kompong Thmar station (Figure 2.6 on the right) indicates a 93 mm (SRES A2) to 145 mm (SRES B2) increase in wet season rainfall and a 63 mm (SRES A2) to 104 mm (SRES B2) decrease in dry season rainfall in 35 years. This means there would be a greater risk of flash flooding and severe drought, which would predispose wet season crops to damage and cause severe water shortages during the dry season.

2.2.2 Irrigation water requirement computation

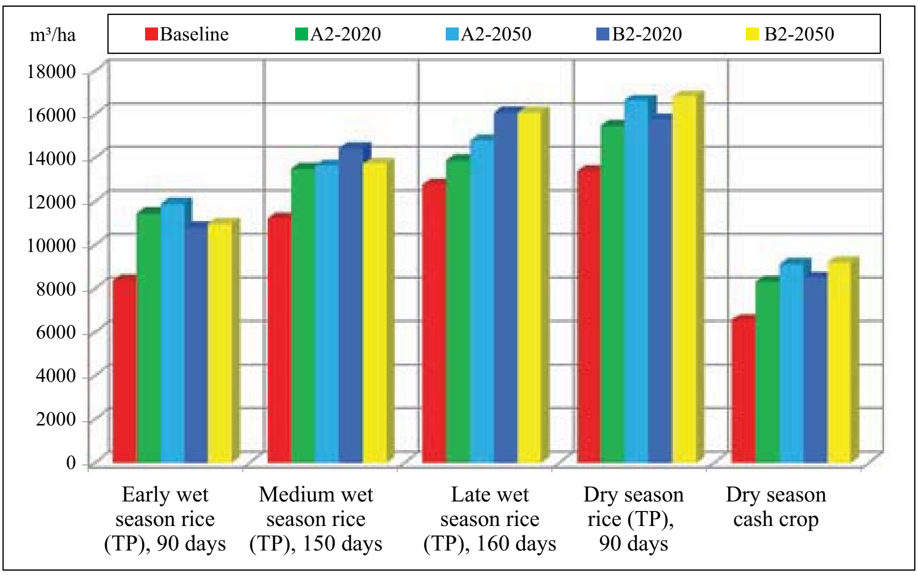
An increase in air temperature would lead to a 0.8 to 2.6 mm increase in monthly evapotranspiration (ETo) rates (Figure 2.7). This significant ETo increase has important implications for planning agricultural irrigation water requirements (IWR) and actions to increase water efficiency, reduce water loss and minimise water waste.

Figure 2.7: Change in mean monthly evapotranspiration rates



Computations for both climate change scenarios (SRES A2 and SRES B2) show that IWR will increase by up to 3000 m^3 per ha in the next 35 years compared with the baseline scenario (Figure 2.8). This significant increase is mainly due to higher ETo rates resulting from higher average temperatures, especially in the dry season. An increase in IWR means greater water supply withdrawals. This emphasises the need for agricultural practices that conserve moisture and minimise water losses, effective water management, new less water-intensive crops and improved irrigation system operation and maintenance.

Figure 2.8: Change in irrigation water requirements in Stung Chinit catchment

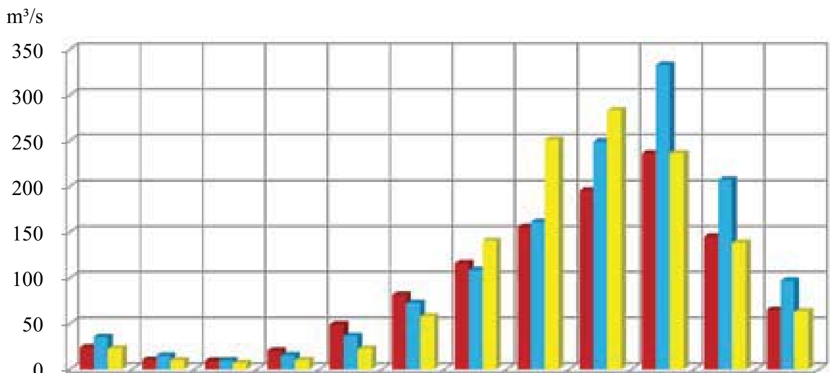


TP = transplanting

2.2.3 Water availability

As shown in Figure 2.9, future flows under climate change would be lower in the dry months and higher in the wet months. Water flows would be lower from November to June under SRES B2 and from March to July under SRES A2. This would lead to irrigation water shortages for dry season crops and affect the early growth stages of wet season crops. Adaptation measures such as adjusting cropping calendars and patterns and managing surplus water during the flood season should be put in place.

Figure 2.9: Comparison of monthly flows for baseline and climate change (2050 projection)

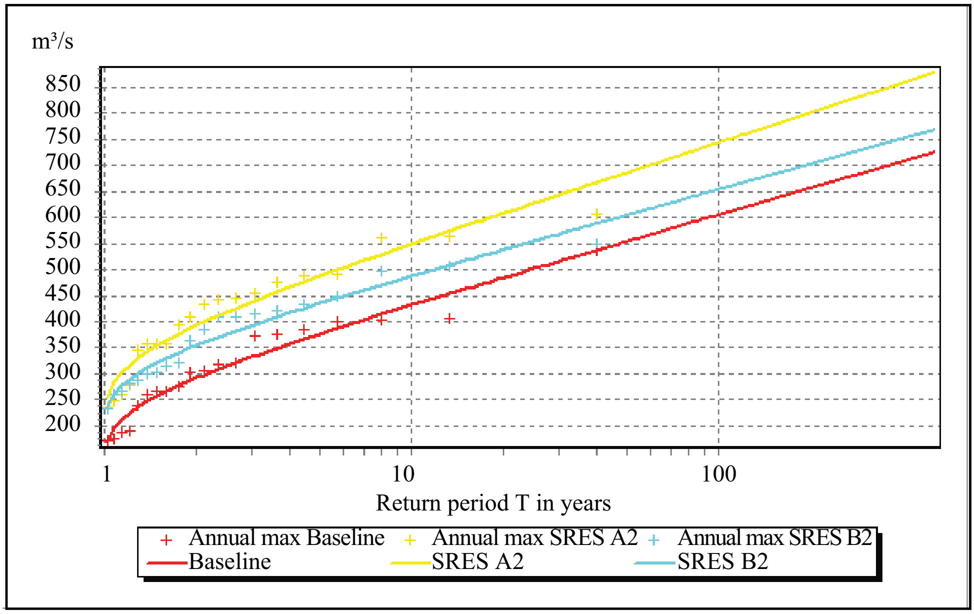


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Scenario Baseline	24.0	10.5	9.1	20.4	49.4	81.4	116	156	195	236	145	65.2
Scenario SRES A2	35.6	15.2	9.9	15.6	36.5	72.3	108	161	249	333	207	96.9
Scenario SRES B2	22.5	9.7	6.6	10.0	22.1	57.5	141	251	283	236	138	63.4

The maximum flows under SRES A2 and B2 would increase significantly by 2050 in comparison with the baseline (Figure 2.10), and average peak flows (2-year return period) under SRES A2 would increase by 34 percent and under SRES B2 by 21 percent. Under SRES A2, maximum flows would increase by 100 m^3/sec (2-year return period) up to 140 m^3/sec 100-year return period), while under SRES B2 maximum flows would constantly increase by about 50 m^3/sec.

This increased frequency and magnitude of peak flows and consequent flood inundation, especially under SRES A2, would damage infrastructure, crops, economic assets, houses and other property.

Figure 2.10: Comparison of frequency curves of maximum flood flows at Chinit irrigation system for baseline and climate change (2050 projection)



Return period (year)	Max flow (m^3/s)			Compare with baseline	
	Baseline	SRES A2	SRES B2	SRES A2 (%)	SRES B2 (%)
2	293	393	355	34	21
5	376	487	435	30	16
10	432	549	488	27	13
20	485	609	539	26	11
50	554	686	604	24	9
100	605	744	654	23	8
200	657	801	703	22	7

2.2.4 Water balance computation

Water balance checking at each scheme outlet tracked water deficit, the magnitude of which can be calculated by subtracting IWR from the net available flow. Deficit occurs when the net available flow is less than IWR To evaluate the safety of water supplies in various irrigation schemes, a factor of 4 out of 5 was adopted as a criterion: in a 20-year period, it is assumed that the scheme will have enough water if the number of deficit years is four or less; in a single year, it is assumed that the scheme will have sufficient water if the deficit period is less than 20 days.

As shown in Table 2.1, the water balance results for both baseline and climate change scenarios indicate that only schemes with well-structured and properly operated and managed reservoirs and more or less complete irrigation channels can meet wet and dry season irrigation demand—to support 100 percent and at least 50 percent, respectively, of the total crop area. Sixteen of the 20 irrigation systems in this catchment cannot provide sufficient water security due to a lack of proper water storage and distribution facilities. Water shortages are expected to occur in the locations where irrigation systems and reservoirs are incomplete and poorly maintained.

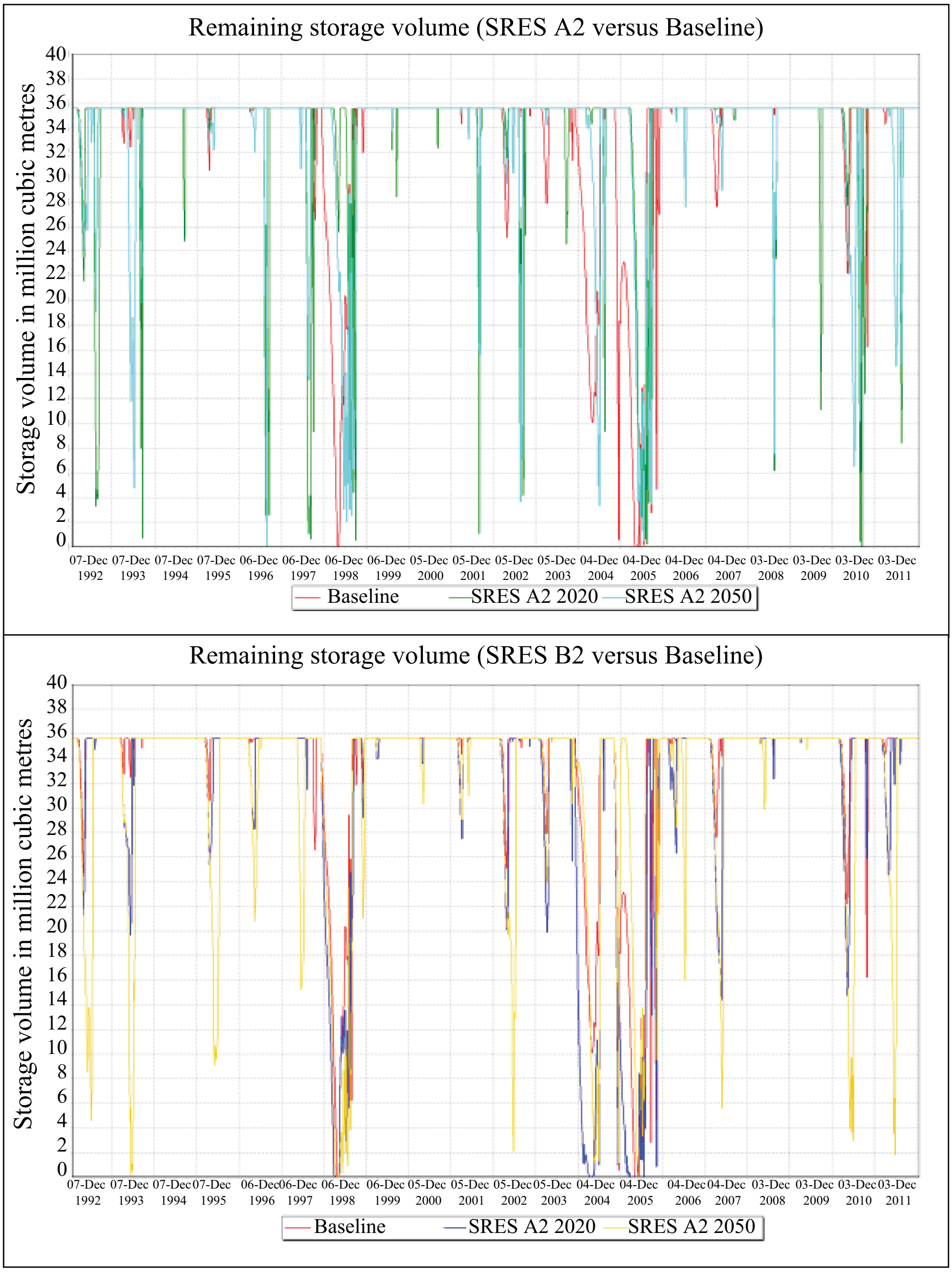
Table 2.1: Water balance analysis for irrigation systems in Stung Chinit catchment for baseline and climate change scenarios

Irrigation scheme	Number of failed years				
	Baseline	A2 2020	A2 2050	B2 2020	B2 2050
Samnab Khachey reservoir	0	0	0	2	0
Veal Thom reservoir	18	18	18	19	19
Tumnub Dei Krohorm	20	20	20	20	20
Tumnub Chuoch	17	20	20	20	20
Tumnub Samroung Chey	20	20	20	20	20
Chamroeun Phal reservoir	16	17	20	20	20
Tuol Meas reservoir	20	20	20	20	20
5 Kompheak reservoir	4	9	7	7	9
Phum Bei reservoir	18	19	19	20	18
Tumnub So Krom	20	20	20	19	20
Tumnub Veal Spor	18	18	18	20	19
O Pha'av	19	20	20	20	20
O Run reservoir	20	20	20	20	20
Dorng Khdar reservoir	20	20	20	20	20
O Tavanh reservoir	3	6	4	5	8
Tumnub O Chek	15	18	15	17	16
Tumnub O Keo Popech	20	20	20	20	20
Stung Chinit irrigation system	0	0	0	3	1
Chong Doung canal	0	0	1	3	1
Tumnub Neang Kong	0	0	0	0	0

Number of failed years	≤ 4	Successful
(in 20-year period)	> 4	failed/not enough water

Only the Stung Chinit irrigation system (Chinit, Chong Doung canal and Tumnup Neang Kong) is in a position to provide a certain level of water security. Under both SRES A2 and B2 (2020 and 2050), water shortages in Stung Chinit irrigation system are likely to be less problematic, occurring in a few years only. However, in some dry years of the baseline computing period (1992-2011), water availability in both Chinit and Taing Krasaing reservoirs could not meet all demands (irrigation, domestic and industrial water uses and environmental flow). This caused the storage to be overdrawn in those drought years. As shown in Figure 2.11, SRES A2 and B2 scenarios would result in more frequent water shortages in Stung Chinit reservoir.

Figure 2.11: Simulation of Chinit irrigation system reservoir water availability after release to meet irrigation and other water uses for baseline, SRES A2 and B2 scenarios



The worst water shortages are expected under the SRES B2 scenario (Figure 2.11 bottom), where downstream flows would be significantly reduced or curtailed during the months of March to July (the start of wet season cropping). Further, new water demands after the 17 irrigation schemes located upstream become operational will put significant pressure on the catchment's water resources, potentially leading to more extensive shortages.

2.3 Implications

Communities in Stung Chinit catchment are primarily agrarian, and adaptation capacity is relatively weak. Numerous infrastructure and land use developments are being undertaken within and outside the catchment. Local people's livelihoods and the natural resources they depend upon are highly susceptible to climate variability and/or extreme climate events, and other human-induced change.

The vulnerability of the communities in Stung Chinit catchment is expected to increase due to their high dependence on natural resources (water, land and forest). For water management and security, the main expected effects are:

- increased maximum and average temperatures: hot extremes and heat waves that lead to substantial water loss through evapotranspiration are very likely to become more frequent;
- very intensive rainfall that can cause frequent flash floods;
- shorter rainy seasons and longer dry spells, which would subject hundreds of thousands of community members to increased water stress.

Both flood and drought are expected to intensify. This increased frequency and magnitude of peak flows and consequent flood inundation, especially under SRES A2, would damage infrastructure, crops, economic assets, houses and other property. Adaptation measures should be put in place, including mainstreaming of climate resilience in drainage and storage capacity design based on predicted flow and water level change, flood management measures and investment in proper maintenance of existing irrigation systems; these have so far been largely neglected.

Water shortages in very dry years are expected to occur more frequently. The worst shortages would occur under the SRES B2 scenario, where downstream flow would be significantly reduced or curtailed during March to July or July to August (the start of wet season cropping and productive period). A disruption to water supply in this period could reduce crop yields and increase the risk of crop failure.

Higher water demands and competing uses are expected when the 17 irrigation schemes in the upstream area come online. This will put tremendous pressure on water distribution and quality in the catchment, and could cause potentially catastrophic water shortages.

Sound water supply management practices, water-smart farming practices and proper irrigation system operation and maintenance are required to minimise water losses and water waste.

Statistical analysis indicates relatively sufficient water resources to meet demand in the Stung Chinit irrigation system for most of the year. In reality, access to sufficient water is a massive problem for some communities and farmers during dry years. Lack of proper distribution systems, unlevelled farmland, distance from water source[3] and lack of a proper water allocation mechanism are the main problems that have to be resolved.

2.4 Suggested ways to improve water security

Adaptation responses for Stung Chinit catchment should be based on needs and priorities in the short, medium and long terms. Responses should focus not only on the most vulnerable hotspots but also on sector-specific plans because agriculture, water resources and infrastructure developments have different implementation timeframes. In general, it is important to:

- ensure water supply for agriculture and domestic consumption in a way that both safeguards agricultural production and enables farm households to increase their productivity and diversify their sources of income;
- strengthen extension support, diffuse a diverse range of seeds (photoperiod-insensitive, drought- or flood-tolerant varieties) and create off-farm livelihood opportunities;
- provide reliable, trusted climate information and tap local knowledge about the creeping risks of changing climate.

2.4.1 Integration of water security and climate change

Even though structural interventions such as irrigation and drainage infrastructure are key to reducing crop and property damage due to flood and drought, adaptation to climate change and disaster risk reduction cannot be undertaken in isolation from strengthening integrated water resource management and addressing community vulnerability due to low adaptive capacity.

3 A study (unpublished) by a project-sponsored scholarship student finds that villages and households benefit from Stung Chinit irrigation scheme differently due to their locality, distance from the system and unlevelled farmland.

Specifically, water resources management in Stung Chinit requires consideration of both supply and demand issues and a greater emphasis on equity, distribution and allocative efficiency. Hard infrastructure and technology interventions (dams, reservoirs, canals, pipes, pumps) should therefore be implemented alongside reforms and/or improvement of political, institutional and governance aspects of water management, access and distribution.

2.4.2 Strengthening integrated catchment development and livelihood support

The development of a river basin management plan that embraces best practices would move integrated water resources management forward. This plan would establish clear expectations of governance and management policies, processes and guidelines to support water resources development, protection and conservation and waste minimisation measures.

As water will not meet all irrigation needs where the schemes are not complete and managed adequately, it is important to promote active participation of the community and users in designing, implementing and maintaining irrigation storage and systems to ensure sustainability and ownership.

The Ministry of Water Resources and Meteorology and its provincial departments should seek to ensure the sustainability of existing irrigation systems, by improving their operation and maintenance and strengthening the role of community-based organisations. In addition, reinforcement of the reservoir and irrigation network is critical to prevent erosion and breach of channels.

Managing supply and demand: Improving water supply and demand management will require significant national, subnational and community capacity building in pro-poor sustainable water resources development and management. For this to happen, basin-wide water-sharing rules, cropping calendars and storage plans have to be established, water accounting and annual water use reporting tools developed, irrigation and drainage systems operated and maintained and water use efficiency improved. With these in place, it should be possible to supply water for supplementary wet season rice irrigation and full dry season rice irrigation. In turn, these mechanisms could also help resolve and allay disputes between upstream and downstream rice farmers over competing water demands for different planting periods.

Surface and groundwater/aquifer: The combined use of surface and groundwater (e.g. from aquifers) has barely been evaluated. Groundwater reserves remain largely underdeveloped and unexploited other than for domestic use. To help spur interest, a pilot project in groundwater recharge as opposed to surface water storage (in order to reduce evaporation losses) should be conducted. Development partners and public and private sector support should be mobilised to investigate and develop groundwater storage as a resource for irrigated agriculture. However, arsenic and other heavy metals are present and have the potential to contaminate groundwater. The risk of this happening and areas needing further investigation should be identified and classified.[4]

Addressing soil quality and productivity issues: Even though water is relatively sufficient for farming around the Stung Chinit irrigation system, rice yield on acidic infertile soils is low, at around 2 tonnes/ha: just enough to cover production costs, or provide a small profit. The director of the Irrigation Service Centre in Stung Chinit observed that farmers from Prey Veng who rent farmland around Stung Chinit can produce rice yields of 4-5 tonnes/ha by selecting improved seed and applying fertiliser before broadcasting.[5] Knowledge transfer among farmers should be supported.

It is important that the ministries of water resources, agriculture and rural development work together at the national and local levels to help communities improve soil fertility, crop production and livelihoods through promoting water security, agricultural intensification (crop diversification, soil suitability and fertility management, livestock and aquaculture) and developing land use planning, crop zoning and cropping calendars.

To avoid maladaptation and residual impacts, communities need support to improve cultivation techniques, livestock practices and manure management to reduce methane emissions from irrigated rice fields, and nitrogen fertiliser application techniques to reduce nitrous oxide emissions, while improving crop yields.

2.5.3 Future research and development

Effective forecasting: Effective operation and management of water resources structures and crop calendar planning require six-month forecasts so that managers can know in advance the water availability and farmers

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4 "What many of these countries have in common are rivers that flow from major mountain ranges (i.e. Himalayas), and that carry with them large volumes of sediment. Arsenic is carried in these sediments which are eventually deposited in riverbanks and floodplains. These processes have taken place for tens of thousands of years, depositing huge amounts of arsenic contaminated sediments. In regions where the groundwater conditions are just right, the arsenic is released from the sediments and dissolved into groundwater aquifers. In populated areas, these contaminated waters are pumped to the surface by wells and ingested by individuals, families, and communities." (Accessed 12 July 2015, www.rdic.org/ground-water-arsenic-in-cambodia.php.)

5 Personal communication, 7 May 2015.

can adjust crop calendars and cropping patterns accordingly. Besides crop planning, medium-term flood and low flow forecasts (for one to three months) are needed for planning gate operation to supply irrigation water.

Hydrometeorological data and climate knowledge management: The fragmented and insufficient hydrological records for the study areas, the very limited stream flow data and the generally short rainfall records are serious constraints and remain one of the central issues that hinder the development of knowledge for informed decision-making. Nonetheless, the current level of knowledge is believed to be sufficient to support decision-making about low-cost or no-regret adaptation measures as long as uncertainties and risks are carefully considered. Concerted efforts to boost climate change knowledge should continue in the medium to long term.

Further investigation of drought issues: In addition to projections for meteorological or climatological drought and hydrological drought, we need to focus on the timing (delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness (intensity, number of events) of the rains. It is important to consider as well water management drought, associated with the decline of water resources due to depletion through different uses and users.

Environmental impacts from land use change: For a better and deeper understanding of the implications of hydrological and ecosystem changes caused by both climate change and shifts in livelihood strategies in the catchment, an additional study of the environmental impacts of land use change on hydrology is inevitable.

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Chapter 3
Stung Chrey Bak Catchment

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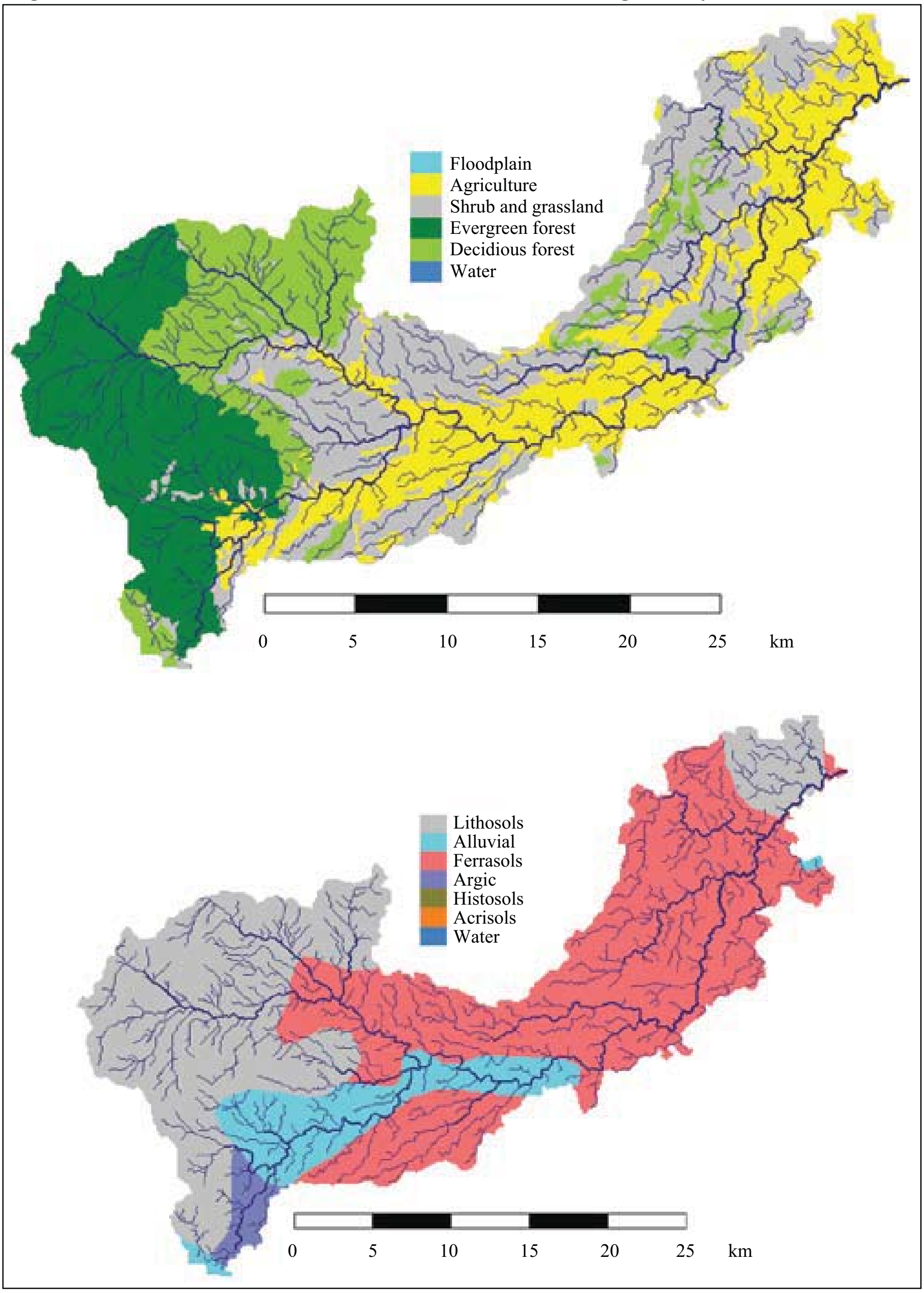
3.1 Physical features of Stung Chrey Bak catchment

The 80-km Stung Chrey Bak stream, a medium-size tributary originating in the Cardamom Mountains, drains water from a total catchment area of 663 km^2 into the Tonle Sap River near Boeng Thom Lake. The main stream runs across two districts, Tuek Phos and Rolear Bier. The river is known by different names to residents along various stretches. From upstream to downstream it is called Stung Srae Bak, Stung Chaktuem and Stung Chrey Bak. The Stung Chaktuem joins the Stung Chrey Bak at Chi Prong confluence (Takab village).

Annual rainfall in the catchment varies between 1400 mm downstream and 2000 mm upstream. Peak rainfall occurs in September-October (MOWRAM 2014). Basically, there is too much water during the rainy season and very little in the dry season. The catchment's hydrology is governed by two contrasting patterns: water discharge starting to increase in early July and peaking in September-October (CNMC 2011), and low flows occurring from November to May (MOWRAM 2014).

Communities in Stung Chrey Bak catchment face water shortages for consumption and irrigation during the dry season, the early part of the wet season and the dry spell within the wet season. Rice farmers rely on irrigation during periods without substantial rainfall. There are several small and poorly designed irrigation schemes which were built in 1975-1978. Despite rehabilitation and development in the 1980s-90s, inadequate operation and maintenance means that the schemes cannot meet demand (Chem et al. 2011). Further, the population in the catchment is increasing, resulting in rapidly rising demand for household use and farming; as of 2011, about 8700 ha of wet and dry rice relied on water from this catchment (CNMC 2011; Chem and Someth 2011). These challenges are further compounded by climate change and poor governance.

Figure 3.1: Land use and soil classification in Stung Chrey Bak catchment



There are six main land use types, with forest dominant upstream and cultivated rice land along the main river. Agricultural land accounts for 55 percent of the catchment area, forestland 32 percent and shrub and grassland 11 percent.

3.2 Findings

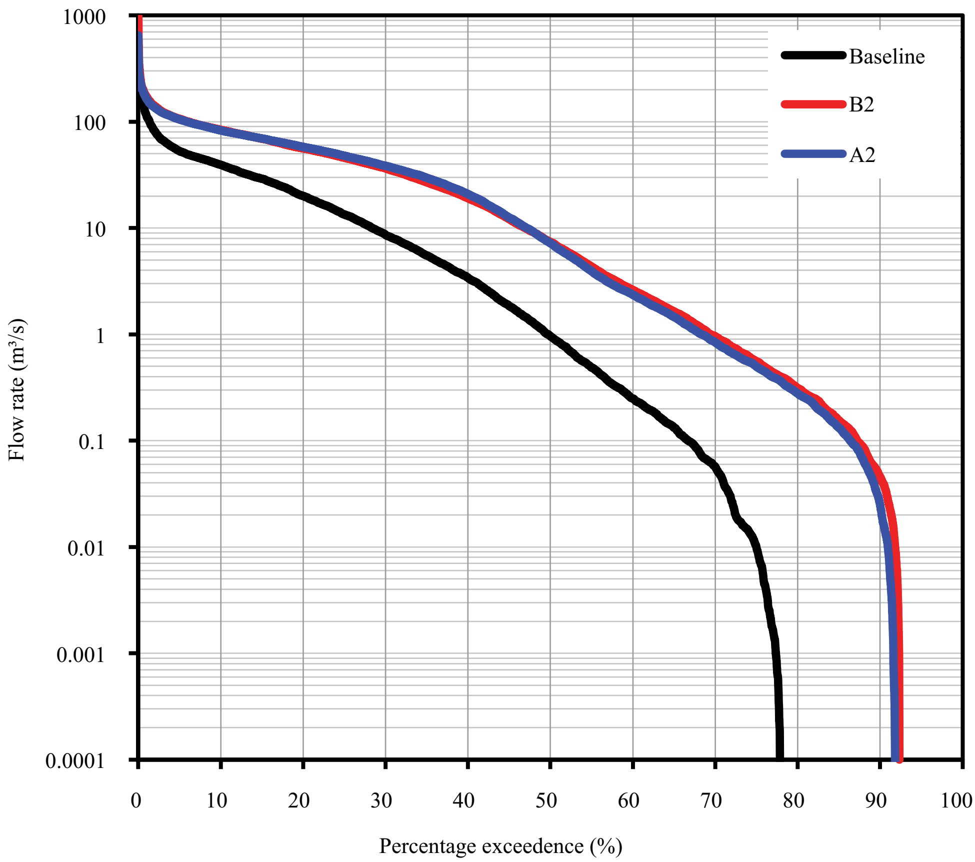
3.2.1 Water discharge simulation results

The calibration of the monthly water discharges at Stung Chrey Bak catchment outlet for baseline (January 1996 to December 2014) and for future emissions scenarios A2 and B2 produced acceptably accurate results relative to observed data.

We estimated the current (baseline) and future extreme floods for a 100-year flood return period. Under the A2 scenario, the mean extreme flood discharge will be about 647 m^3/sec, and in the B2 scenario about 1170 m^3/sec.

The 100-year floods were estimated at nearly the same value for the baseline and A2 scenarios but much lower than the value of the B2 scenario.

Figure 3.2: Flow duration curves for the three scenarios (logarithmic scale, base 10)



Flow duration curves for the three scenarios were computed. A flow duration curve represents the relationship between the magnitude and duration of stream flows; duration here refers to the percentage of time that a particular flow is exceeded. The shape of the flow duration curve for any river strongly reflects the type of flow regime and is influenced by the characteristics of the upstream catchment including geology, urbanisation, artificial influences and groundwater.

As Figure 3.2 shows, peak flows under the future climate scenarios are much higher and low flows are lower than for the baseline period. This means that droughts and floods will be more extreme. Droughts will occur more frequently while floods will be less frequent but more severe.

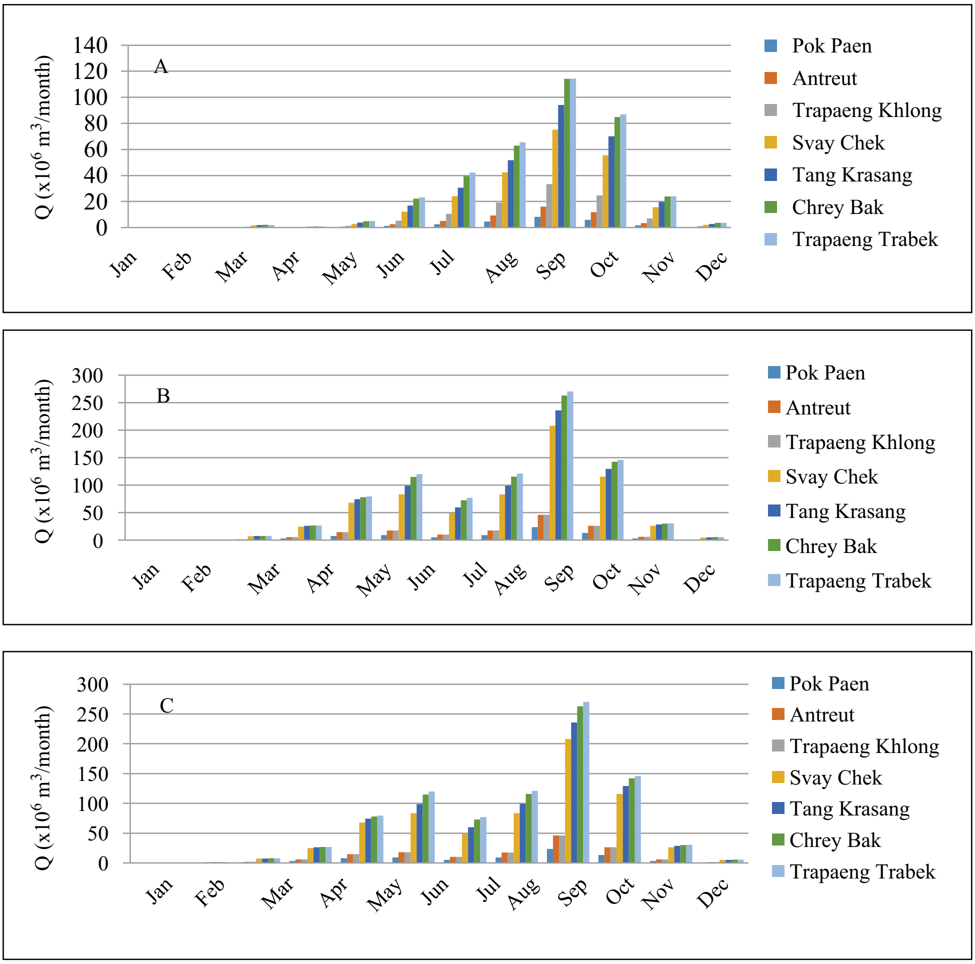
3.2.2 Water availability in the irrigation schemes

There are seven irrigation schemes in Stung Chrey Bak catchment, and there are seasonal variations in water availability. In the baseline scenario, water discharges gradually increase from May, peak at 270MCM in September, fall from October to December and then level out until April. Figure 3.3 depicts water availability in the different irrigation schemes under baseline and future climate scenarios.

The water balance (water availability against water use) calculations indicate that, statistically, in most of the irrigation schemes, there are no water shortages. Access to dry season irrigation theoretically enables farmers to switch from wet season rice to more profitable dry season rice cultivation while growing short maturing rice varieties and/or cash crops during the wet season (UNDP/GEF 2013). However, Tang Krasang scheme often experiences water shortages in the dry season. For the rice farmers who grow IR-66 (110-day variety) in the dry season from mid-December to late March, the scheme lacks 9262 m^3 in February and 47,752 m^3 in March, resulting in water scarcity during the critical stage of ripening (IRRI 2007).

Under both future climate scenarios there is sufficient water available for both wet and dry season cultivation. Yet downstream farmers often report a lack of water for rice cultivation. This represents management drought, because the water shortages are created by poor management of water and poor operation and maintenance of infrastructure.

Figure 3.3: Water availability of irrigation schemes under three different scenarios



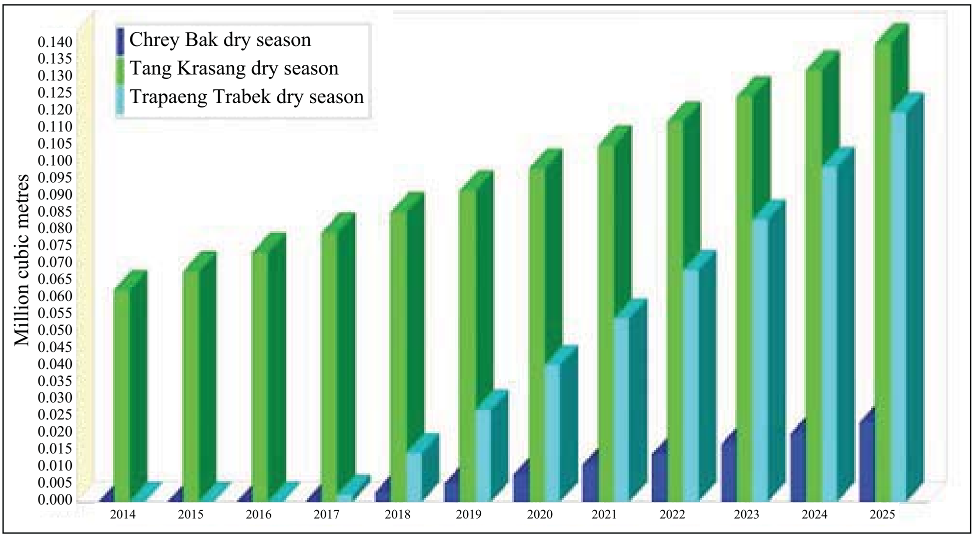
If the irrigated area for dry season rice increases by 5 percent a year from 2014 to 2025, there will most probably be water shortages for dry season irrigation in at least three irrigation schemes, as follows:

Tang Krasang is the largest rice irrigation scheme in the catchment. The dry season irrigated area will expand from 120 ha in 2014 to 195 ha in 2025. The demand for water will increase from 0.44 MCM to 0.67 MCM. As of 2015, Tang Krasang has a shortfall of 0.06 MCM, but in 2025 farmers will need 0.14 MCM more. This means that there is no possibility of increasing water use. Thus it will be necessary to manage water demand by growing crops and rice varieties that demand less water, or to change water allocation and cropping calendars.

Chrey Bak scheme's command area of 105 ha in 2014 will grow to 171 ha in 2025, and water demand will increase from 0.38 MCM now to 0.59 MCM in 2025. There is enough water to irrigate dry season rice until 2016, but the scheme will meet water scarcity from 2017 onwards. It will require an additional 367 m^3 in 2017 and an extra 24,383 m^3 in 2025, less that that needed in Tang Krasang and Trapaeng Trabek schemes

Trapaeng Trabek is located near Boeung Thom Lake and is inundated by the Tonle Sap flood pulse every year. The command area for dry season rice will increase from 500 ha now to 831 ha in 2025. The irrigation demand will increase from 1.87 MCM now to 2.86 MCM in 2025. There will be enough water for irrigation until 2017. But an additional 0.01 MCM will be needed in 2018. In 2025, there will be a shortfall of 0.12 MCM to irrigate dry season rice. It will therefore be necessary to manage water demand and water allocation and/or change cropping calendars.

Figure 3.4: Dry season water scarcity with 5 percent annual increase in irrigated area, 2014-2025



3.3 Implications

Climate change is expected to increase the frequency and intensity of drought in Stung Chrey Bak catchment. If farmers use only surface water, they will face increasing water scarcities for dry season cultivation. Biodiversity and ecosystems will most likely be affected, too. Local people's vulnerability to natural hazards will increase due to their direct dependence on surface water and river ecosystems for their livelihoods.

Flooding will be less frequent but more severe and destructive; infrastructure such as irrigation canals, dams and roads could be severely damaged. Communities would face more difficulties.

Water is sufficient for only the currently irrigated area. If water demands continue to increase due to expansion of irrigation command areas, water security will be badly affected. Ongoing mismanagement of water sharing and allocation, along with water insecurity, will intensify upstream-downstream conflicts over water.

3.4 Conclusion

The conclusions and key findings can be summarised as follows:

- In theory, some irrigation schemes have sufficient water to supply both dry season and wet season rice cultivation (baseline). But, in reality, water conflicts between upstream and downstream communities have broken out.
- In the future floods will be much higher and low flows will be lower than the baseline values. There will be more extreme droughts and floods along the Chrey Bak River.
- If the irrigated command areas remain unchanged, water scarcity will probably not be a problem. But if the irrigated areas increase by 5 percent annually, Tang Krasang, Chrey Bak and Trapaeng Trabek irrigation schemes will face water shortages for dry season cultivation. This necessitates better land and water management in these schemes.

3.5 Suggested ways forward

The study strongly suggests the following actions:

- The Department of Water Resources and Meteorology (DRWM) should support farmer water user communities (FWUCs) in improving irrigation and farm water management, water allocation, water storage and operation of water gates.
- Local authorities, DRWM and FWUCs should mobilise support for redesigning and improving water infrastructure such as reservoirs, sluice gates and canals along the Stung Chrey Bak so that water delivery to irrigated areas is more efficient.
- Farmers need to improve farm water management by reducing irrigation water loss, especially during the dry period. Applying a suitable cropping

pattern would also be helpful for sound water allocation. The Department of Agriculture, DWRM and FWUCs should actively support farmers by providing technical assistance and conflict mediation.

- Local authorities, DRWM and FWUCs should explore the use of groundwater for increasing dry season cultivation because surface water in the river system is fully used. Knowing groundwater quantity will be helpful for irrigation expansion and drought management.
- Improving catchment management by restoring degraded forest in upstream areas should be considered to increase forest cover, prevent flash flooding and sustain dry season flows.
- MOWRAM and MAFF need to strengthen FWUCs. Community members should be provided capacity building in water management, water regulations and downstream-upstream conflict resolution. Mechanisms, rules and regulations on water use and water fees should be adopted for the whole catchment.

3.6 Future research and development

More in-depth research is needed on the following topics:

- Improvement of irrigation water allocation
- Building adaptation to flood and drought in Stung Chrey Bak catchment
- Impacts of land use change on water and sediment, and implications for integrated watershed management
- Improved understanding of surface water and groundwater for sustainable water resources management.

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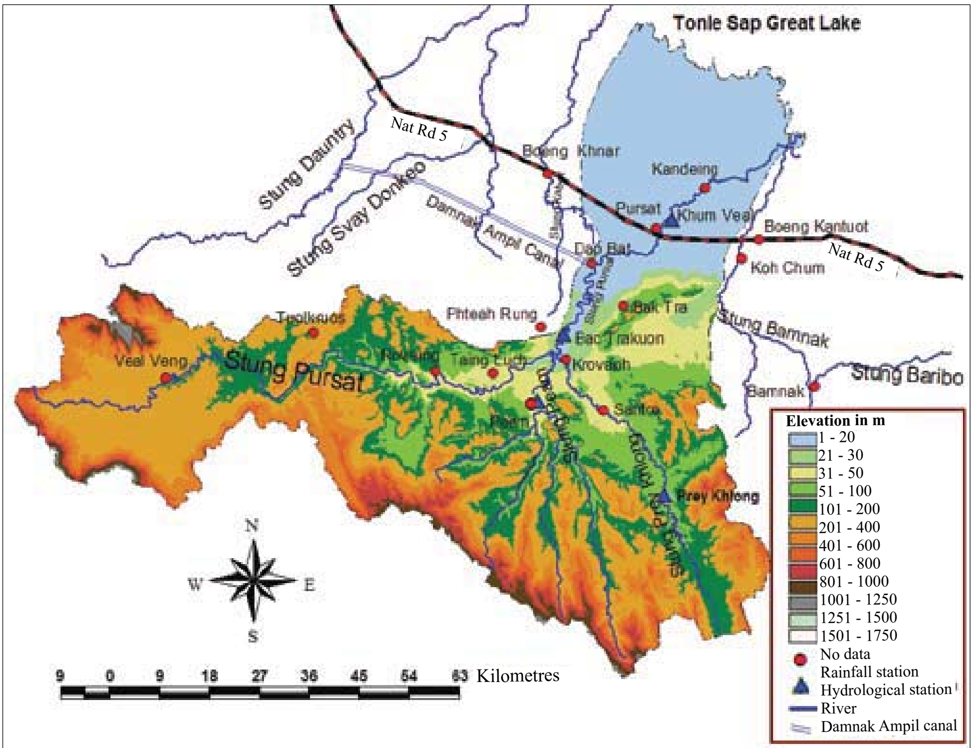
Chapter 4
Stung Pursat Catchment

Mao Hak, Toch Bonvongsar

4.1 Physical features of Stung Pursat catchment

Stung Pursat catchment is located in Pursat province, south of the Tonle Sap Lake, and drains an area of 5955 km^2 (Ashwell et al. 2011). The catchment is shared by six districts: Veal Veng, Kravanh, Sampov Meas, Krakor, Bakan and Kandieng (CNMC 2011). With an annual average discharge of 2818 MCM into the Great Lake, Stung Pursat originates on the drier eastern slopes of the Cardamom Mountains and flows for approximately 150 km (JICA 2011). Two main tributaries, the Stung Peam and Stung Santre (Prey Khong) rivers, flow in a northerly direction and meet the Pursat River just above Bac Trakuon (CNMC 2011; JICA 2011).

Figure 4.1: Digital elevation model of the Stung Pursat catchment and hydrometeorological monitoring stations



Source: MK16 2013a

The climate is influenced by tropical monsoon systems, with a distinct wet season from May to November bringing approximately 90 percent of total annual rainfall, and a dry season extending from December to April characterised by hot and dry air with high potential evapotranspiration during March and April (CNMC 2011).

The Elephant and Cardamom ranges have lower precipitation totals, ranging between 900 and 1800 mm in normal years, and between 800 and 1500 mm in dry years (MK16 2013a). Elevations in the Pursat catchment range between 6 and 1717 m above sea level (masl).[1] More than 75 percent of the catchment terrain is hilly, with an elevation greater than 30 masl, and is covered by forest of varying densities (JICA 2011). Major soil types in the catchment are: Dystric Leptosol and Cambisol in the upper reaches, Gleyic and Plintic Acrisols in the mid-elevations and Dystric Fluvisol and Dystric Gleysol in the lower reaches (CNMC 2011; MK16 2013b).

Agricultural land is reported to have expanded at an estimated annual rate of 1.5 percent in the last 10 years, from 39,979 ha in 1999 to 42,301 ha in 2004 and 46,329 in ha in 2009 (CNMC 2011). The maximum growth between 1999 and 2009 in Stung Pursat was in dry season rice (3.0 percent), slightly higher than that of non-rice crops (2.8 percent) (MK16 2013a). However, the growth in wet season rice crops in Stung Pursat was consistent with that in the entire subarea, amounting to 1.3 percent. Agricultural activities now include more non-rice crops, especially cash crops, indicating a shift from traditional subsistence agriculture (MK16 2013c).

4.2 Stung Pursat social and demographic dynamism

The population of Pursat province is about 397,000 with more than 203,500 (over 51 percent) living in Stung Pursat catchment, which occupies 77 percent of the province (MK16 2013b). The province has a young population and a falling total fertility rate. This indicates the beginning of a major transition in its population and human resource base to one dominated by productive age groups, creating both opportunities and challenges. Annual average population growth between 1998 and 2008 in Cambodia was 1.54 percent, while in Pursat it was estimated to be 0.77 percent (MK16 2013b).[2] Settlements are mainly along the Pursat River and within 50 km of both sides of National Road 5 and Pursat city.

Dependence on the Stung Pursat’s water and related resources is very high and exists beyond the hydrological boundary of the catchment, due to various water diversions and trade with neighbouring districts and provinces. A

1 Elevations referenced to mean sea level based on the Ha Tien datum, Vietnam.

2 The discrepancy between the two growth rates is due to factors such as a lack of surveying in 1998 because of insecurity and emigration from Pursat to other provinces and Thailand.

portion of the Stung Pursat flow is diverted through Damnak Ampil weirs to Svay Don Keo and Maung sub-basins. These diversions are particularly critical for the rural poor, who depend heavily on subsistence livelihoods (MK16 2013c).

4.3 Existing and planned water infrastructure

Water resources in Stung Pursat catchment are increasingly under pressure due to significant increases in paddy rice production and irrigated area and diversion of water to neighbouring catchments for agriculture (MK16 2013c). To alleviate this situation, a series of irrigation, reservoir and hydropower projects have been implemented or are being planned. In total, there are 12-17 large and medium-size existing and planned irrigation areas, including three in nearby Svay Donkeo River sub-basin, amounting to 55,509 ha relying on water from the Stung Pursat (JICA 2013).

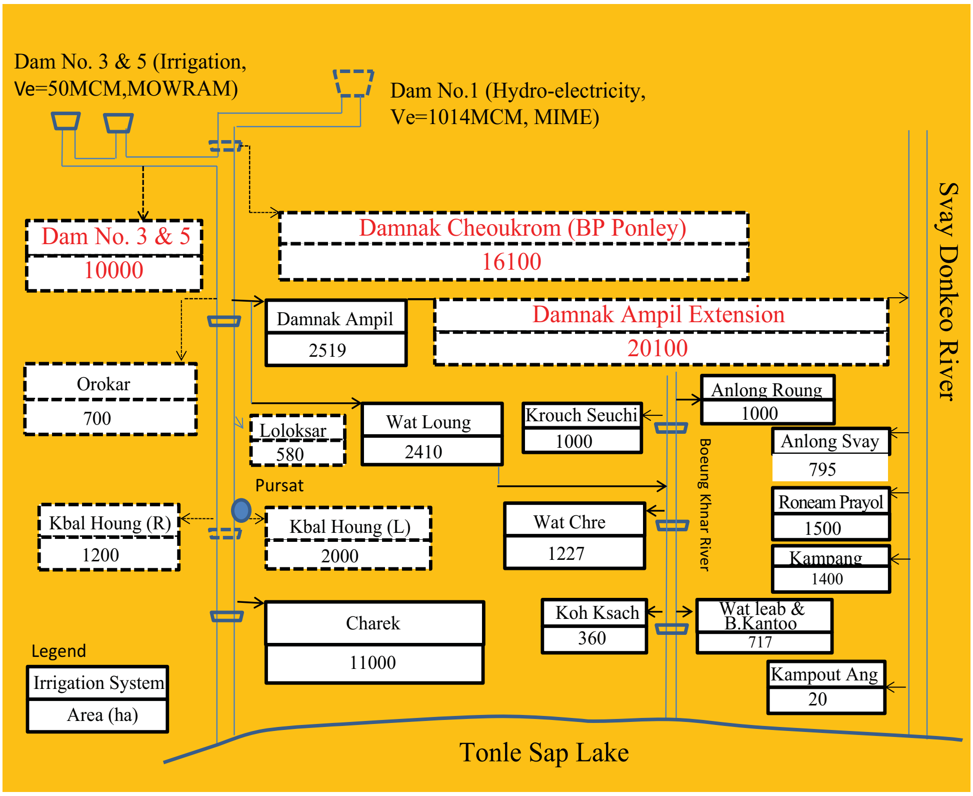
Table 4.1: Summary of water resources infrastructure projects in Stung Pursat catchment

Water resources infrastructure	Storage volume (MCM)	Command area (ha)	Existing	Under Development	Planned
Dam # 1	1014	-			✓
Dam # 3	25.5	-	✓		
Dam # 5	24.5	-	✓		
Damnak Cheukrom irrigation scheme	n/a	16100			✓
Damnak Ampil irrigation scheme-extension	n/a	15000	✓		✓
Damnak Ampil - subproject	n/a	2519			✓
Orokar irrigation scheme	n/a	4700	✓		
Loloksar irrigation scheme	n/a	580	✓		
Wat Loung irrigation scheme	n/a	2410			✓
Kbal Houng irrigation scheme (right bank)	n/a	1200	✓		
Kbal Houng irrigation scheme (left bank)	n/a	2000	✓		
Charek irrigation scheme	n/a	11000	✓		
Total command area		**55509**			

Note: Irrigation command areas are for the wet season. Damnak Ampil headworks command area is 24,629 ha and is the sum of Damnak Ampil scheme extension, Damnak Ampil subproject, Orokar and Wat Loung irrigation schemes.

Source: JICA 2013

Figure 4.2: Schema of water resources development in Stung Pursat catchment



Source: JICA 2013

The Stung Pursat is the only tributary of the Tonle Sap Lake with more than one hydrometric station. Over the years, water level data has been collected by 13 stations, of which only six are operational. All stations are located at mid to low elevations (MK16 2013a). Bak Trakuon is the hydrometric station with the longest data records, from 1995 to 2011. However, Pursat rainfall station has longer data records (1981 to 2011) and was used as the representative station for the low elevation parts of the catchment. Kravanh rainfall station has 17 years of data (1994 to 2010) and was used as the representative station for the mid-elevation areas.

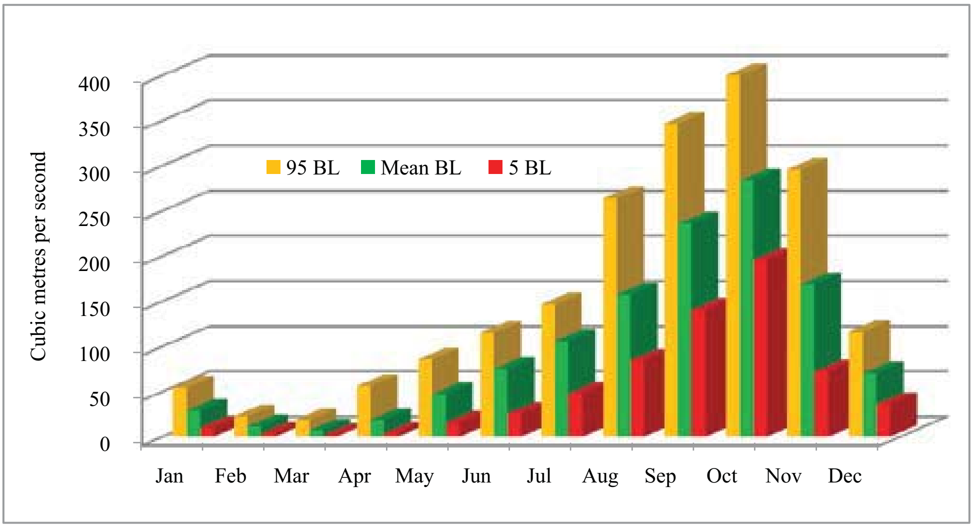
The water balance of the subcatchment was calculated to find out what the water demands are and will be for irrigation, domestic use, industry, energy generation and instream/environmental flows. The water balance computation was carried out for a baseline scenario and climate change scenarios (for 2020 and 2050) under SRES A1B (ECHAM4 climatic data downloaded from SEA START).

4.4 Findings and implications

4.4.1 Baseline stream flow conditions

Analysis of 24 years of flow data at Damnak Ampil headworks in midstream indicates that the lowest flow occurs in March. The highest flow in Stung Pursat River normally occurs in October, leading to inundation in many places.

Figure 4.3: Flow conditions in Stung Pursat, baseline conditions (1995)



4.4.2 Flow change under A1B scenario

River flow estimates under scenario A1B show that flow availability in Stung Pursat River is significantly different for each month. Monthly flow will increase at the beginning of the wet season because the rains will arrive earlier, in May and June. In the long term, it is highly probable that flows will exceed expectations in September-October, and potentially lead to extensive flooding downstream, including in Pursat city, the major administrative and economic centre of the province.

The mean daily flow in current conditions and A1B scenario demonstrate a significant change in flow patterns, especially in May-June, at the beginning of the wet season, and in September-October, during the critical stage of wet season rice production.

In the long term, the catchment will experience an early start of the rainy season followed by a drought window in May-July (delaying wet season farming). This drought will damage rice seedlings and affect broadcasting. Then flooding will take place in August and September, which is a critical period for replacing damaged crops, and a longer drought window will open in October during the reproductive (panicle initiation to flowering) and ripening (flowering to mature grain) stages. For many farmers, disruptions to freshwater availability during this particular period will have significant impacts.

Figure 4.4: Mean monthly flows, baseline and A1B scenario

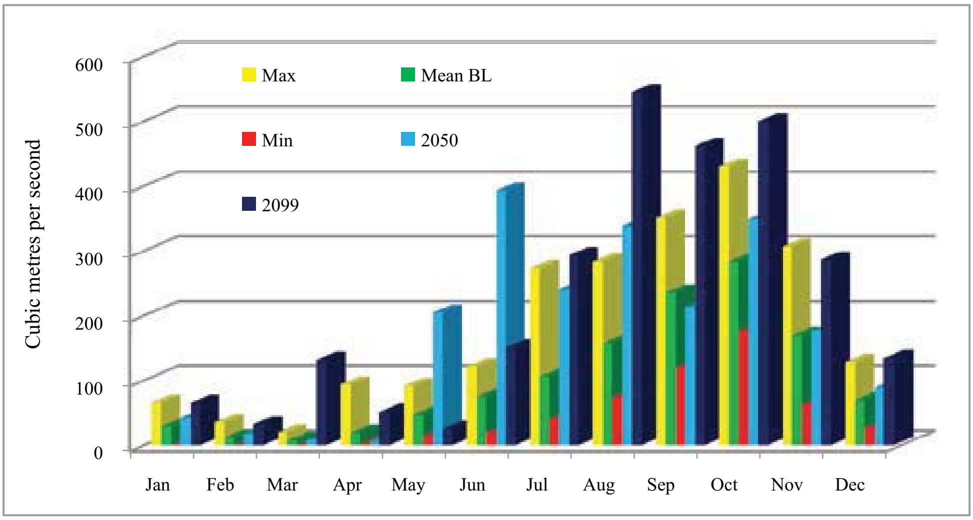
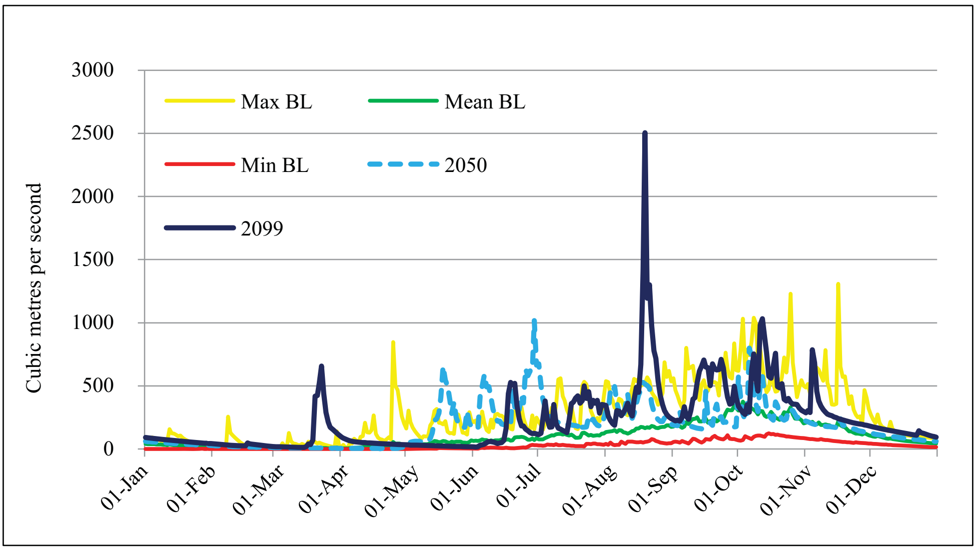


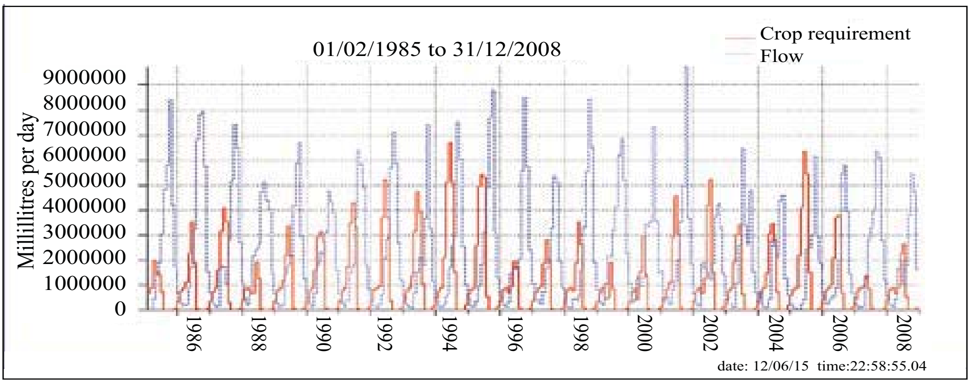
Figure 4.5: Mean daily flows, baseline and A1B scenario



4.4.3 Irrigation water requirement

The results of the water balance[3] show that water will not be sufficient to meet requirements for farming; even in current conditions, irrigation demand is higher than water availability and irrigation loss. Figure 4.6 shows the daily crop water requirements, available flows and irrigated areas for rice cultivation at Taing Louch and Damnak Chheu Krom. Monthly crop water demand and supply will not be properly synchronised because water may not be available when it is most needed by downstream communities.

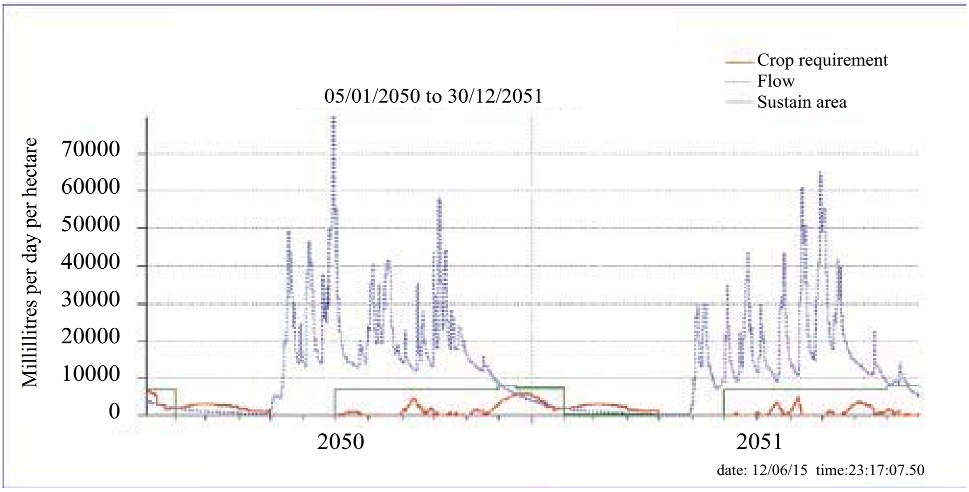
Figure 4.6: Projected crop water requirements against flow availability at Taing Louch and Damnak Chheu Krom

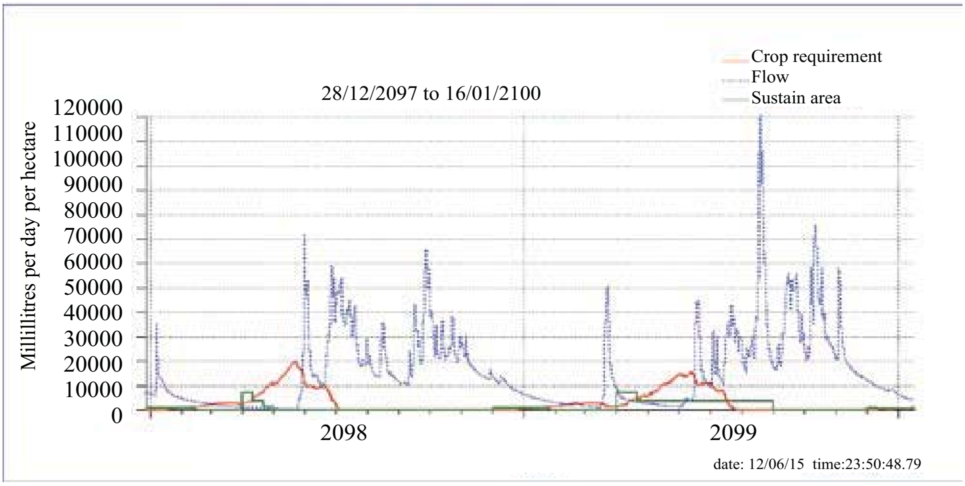


As further shown in Figure 4.7, there will not be enough water for paddy rice farming in many locations due to a significant decrease in the flow of water in the river during the dry season. And in the wet season there will be increases in flood frequency and magnitude and, consequently, in flood damages.

3 Taking into account inflows of all the branches of the Pursat River, irrigation return flows, effluent return and interbasin diversions, against water demands of the usage sectors including consumptive (irrigation, homes and industry) and non-consumptive (hydropower, environment and navigation) uses.

Figure 4.7: Daily crop water requirements, available flows and irrigated areas





4.5 Key findings and implications

For water management and security in Stung Pursat, the main expected effects are as follows.

1. As a result of highly probable warmer and wetter climate conditions prior to 2050, changes in catchment runoff and flood levels are expected (IPCC 2007).

2. Wet season rains will start earlier but rainfall will dip during the start of wet season rice cultivation. In the middle of the wet season, the flow in the river will be significantly increased from the current situation. This could lead to overbank flow along many reaches of the river, especially in Pursat city and downstream.

3. Flooding will be most severe near and around Pursat city, where the average annual peak daily flow will increase by 20 percent and the maximum annual peak in the 24-year period by 35 percent. This will require a significant investment in land use management, flood control and drainage facilities at key places.

4. More pronounced fluctuations in flow in both dry and wet seasons is expected. The high and low flows will make it much more difficult to cultivate and harvest crops without significant improvements in irrigation and drainage systems, proper planning, enforcement of water use restrictions and proper water allocation.

Results from the water balance simulation revealed that water supply, under both baseline and climate change scenarios, would not meet the needs for all irrigation schemes in the catchment at all times. A rapid increase in irrigation demand is observed in the lower part of Stung Pursat catchment in the dry season, and in the neighbouring catchments of Svay Donkeo and Beung Khnar rivers.

It is expected that Dams No. 3 and 5 (completed in 2015 but not yet fully operational) will provide some flow regulation both for flood and drought management, and they would be theoretically sufficient to support all existing and planned irrigation schemes in Stung Pursat, Beung Khnar and Svay Donkeo catchments.

Even though water resources seem to be available to meet demand in many schemes of the Stung Pursat, in reality, access to water for some communities and farmers will continue to be problematic. This is due to a lack of proper farm irrigation systems (no concrete lining causing high water loss, water gates deterioration and high pumping costs), distance from a water source, significant irrigation loss, and lack of proper water allocation (MK16 2013b).

New non-agricultural and agricultural water uses in both upstream and downstream parts of the catchment will put significant extra pressure on the catchment's water resources, potentially leading to more extensive water shortages in the early dry season.

Poor access to water is compounded by suboptimal management, maintenance and operation of existing irrigation schemes due to lack of technical expertise, financial resources and community-based organisation or governance.

Furthermore, with the present earth irrigation canals and poor water gates operation and maintenance, water loss will remain extremely significant unless irrigation efficiency is improved and water loss from evapotranspiration reduced (Provincial Validation Workshop 2015). Considering water demands, water loss and storage capacity, water shortage is expected in very dry years, which may occur more frequently.

Stung Pursat catchment management clearly requires strong coordination among different players such as dam operators and upstream and downstream water users during critical times such as abnormal flooding and drought.

4.6 Suggested ways forward

Adaptation responses for the study site are proposed based on short-, medium- and long-term needs and priorities for agriculture, water resources and infrastructure sectors, which have different implementation timeframes.

Principal suggestions:

- Given that the vast majority of agriculture is reliant on seasonal rainfall, development of irrigation infrastructure, especially an effective water storage and distribution system, is a key solution to reducing the vulnerability of farmers to shifting climate patterns.
- Management of water resources in Stung Pursat in the face of climate change requires consideration of both supply and demand, placing a greater emphasis on equity, distribution and efficiency. Hard infrastructure and technological interventions for water resource management should therefore be accompanied by reforms and/or improvements in political, institutional and governance aspects of water management, access and distribution.
- Adaptation to climate change in agriculture cannot be undertaken in isolation from the water resource sector or national rural development.
- Action on these recommendations will require much lobbying to ensure change in attitudes and positions.
- Action on financial and human resources and physical barriers will require the integration of resource concerns in policy and implementation and the identification of synergies with the Sustainable Development Goals.

Specifically, the following actions and supports will be required for integrated water resources management at catchment scale:

1. Water resources development in Pursat catchment must be enacted through local, provincial and national stakeholders to reduce the gaps between ideal and actual governance.
2. The Ministry of Water Resources and Meteorology and its provincial departments in Pursat and Battambang should pay urgent attention to ensuring the long-term sustainability of existing irrigation systems, improving operation and maintenance, and strengthening the role of community-based organisations. Also critical is reservoir and irrigation network reinforcement.
3. An appropriate river catchment plan needs to be formulated and implemented to support water development and water resources protection and minimise water impacts.
4. Water allocation and reservoir capacity sharing to promote efficient water use rely on proper institutional structures, appropriate decision-support tools, good water measurement infrastructure and reliable water accounting systems.
5. To address mismatch between water demand and supply at critical times and locations, appropriate varieties, cropping patterns and calendars should be adopted as climate change and competing water demands affect rice and dry season cropping.

4.7 Future research and development

The following research and development should be carried out:

1. Long-term river forecasts (six months) are needed to know in advance the water availability for planning crop calendars and selecting cropping patterns. Medium-term flood and low-flow forecasts (one to three months) are also needed for planning gate operations.
2. It is urgent to address the very limited stream flow data and rainfall records to support knowledge for decisions on low-cost or no-regret adaptation measures.
3. It is critical to establish comprehensive and integrated drought indicators that incorporate climate, soil and water supply factors, as well as social, environmental and institutional aspects.

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PART 2

Participatory Assessment of Key Elements of Vulnerability

Chapter 5
Vulnerability Assessment in the Three Catchments

Sam Sreymom, Kim Sour, Nong Monin, Sarom Molideth

5.1 Background

Before conducting the assessment, the study team conducted a systematic and comprehensive review to determine the validity and applicability of an array of approaches used by previous studies, including participatory tools and methods for climate change vulnerability and adaptation (V&A) assessment (Kim et al. 2014). Based on that review, the project partners adopted a participatory assessment of sensitivity and adaptive capacity as the best way to gather local insights towards promoting a mutual understanding of how rural communities experience and cope with ongoing climate change impacts.

This chapter starts with the mapping of vulnerability hotspots in the three catchments. After a description of the methodology, the findings discuss the three components of vulnerability: exposure, sensitivity and adaptive capacity. Finally, we draw conclusions on the extent of vulnerability in the study catchments, and suggest what can and needs to be done to build resilience.

5.2 Initial climate vulnerability hotspot mapping

Vulnerability mapping using information gathered from the literature review and focus group discussions showed all three catchments to be highly vulnerable to climate change and disaster risks. The maps in the following sections provide a useful visual snapshot of vulnerability at different temporal (last 10 years) and spatial scales. They also helped determine the scope of the study, identify key informants and finalise the design of an in-depth participatory V&A assessment.

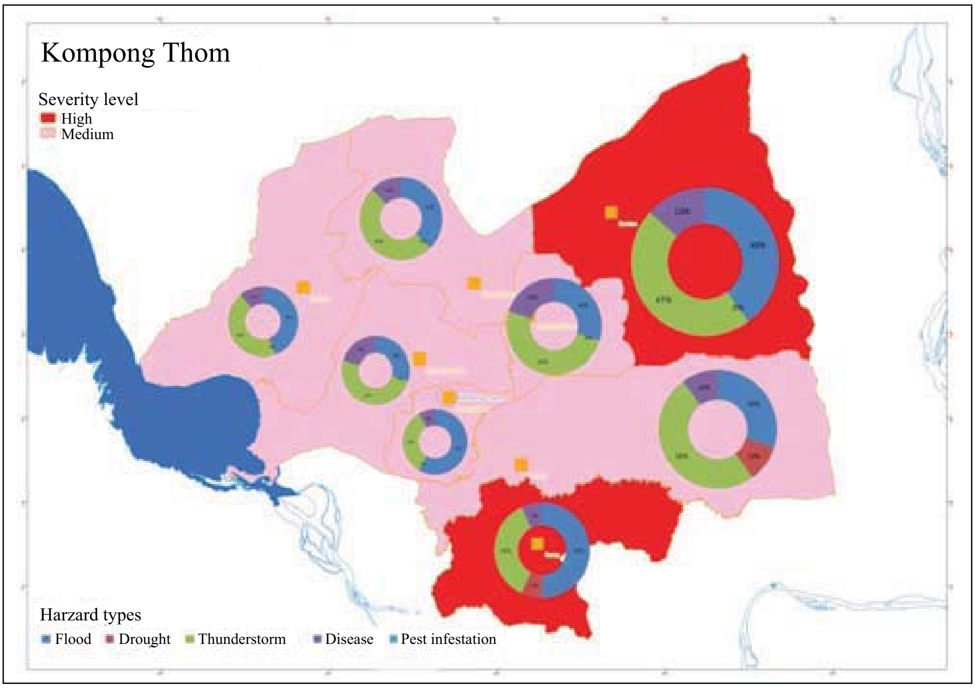
The maps presented in the following sections were generated from single indicators (frequency and magnitude of floods, droughts and other disasters) and used to define climate change hotspots for further investigation of sensitivity (population density and land use change) and capacity to cope (poverty headcount, access to early warnings, social support and mutual-help groups).

5.2.1 Stung Chinit catchment, Kompong Thom province

The province is no stranger to flooding, and there have been numerous floods in Kompong Thom since 1961. But floods have occurred more frequently since 2000, destroying houses, crops and public infrastructure (Chem and Kim 2014). Almost all of the rice fields in Santuk and Baray districts were destroyed by flood in 2000. Flooding also damaged 97 ha of rice and 30 ha of other crops in Baray district in 2006, and 133 ha of rice and 566 ha of other crops in Santuk district in 2006 and 2007. Again, in 2011, rice fields in both districts were almost completely inundated. There were also reports of drought and storms in 2003 and 2012.

Overall, the assessment identified Sandan district as the most affected and Baray and Santuk districts as the most vulnerable to climate hazards (Chem and Kim 2014).

Figure 5.1: Types and severity of natural disasters in Kompong Thom



Source: Provincial workshop, 2014

The high sensitivity to climate change in Baray and Santuk districts is associated with the high population densities in those areas. Baray has 188,551 inhabitants of whom 96,900 are women; Santuk has 83,777 inhabitants, 43,023 of them women (NCDD 2010). Poverty and high population density both exacerbate vulnerability and hinder adaptation to climate change. Typically the poor are the hardest hit because they do not have the resources, access to information and services or means to deal with, protect themselves and recover from natural disasters. For example, floods and storms can badly damage crops and leave farmers in Stung Chinit without rice seed for the next planting; and they are not able to recoup their losses by growing rice in the dry season because of regular pest infestations (Chem and Kim 2014).

Importantly, irrigation systems are not being effectively managed and repaired and maintained, and upstream-downstream water allocation is unbalanced. Irrigation service fees are not being collected, for instance. Another factor that heightens sensitivity is land use change and the associated clear felling of forest. Kompong Thom Forestry Cantonment forecast that significant forest cover will be lost by 2018 because of forest clearance by local people and land concession companies (Chem and Kim 2014).

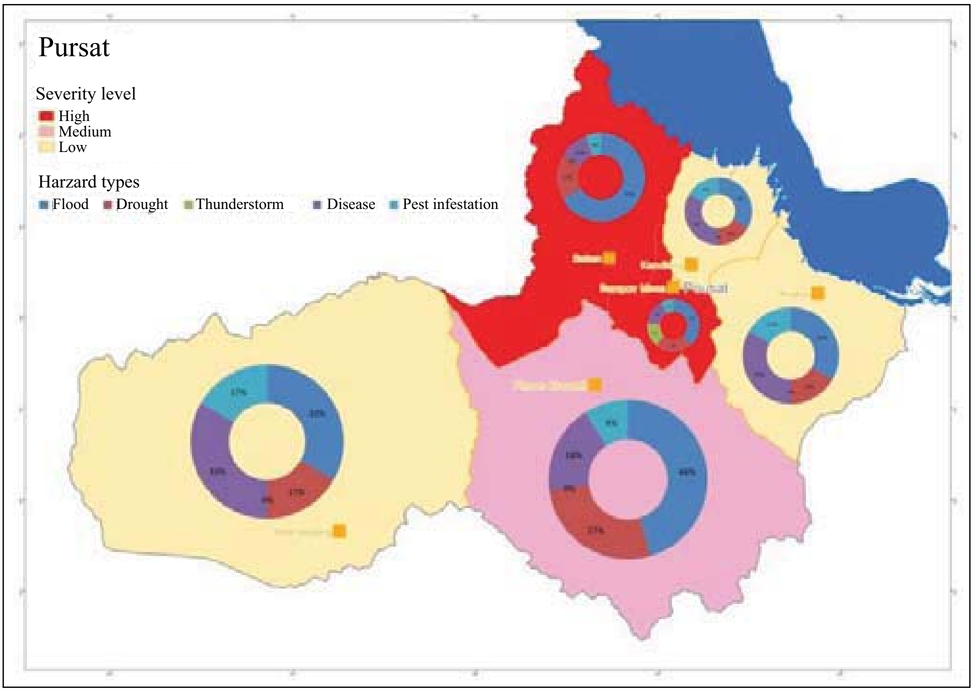
Although some mechanisms exist to help people adapt to climate change, cooperation between relevant institutions and authorities at all government levels is limited. This lack of institutional cohesiveness, coupled with a lack of financial and human resources, materials and equipment, can be linked to the absence of effective outreach with local communities. As a result, communities are insufficiently prepared to cope with the climate hazards they face. Basic knowledge about climate change is limited, as are the necessary skills to understand climate risks and the need for adaptation. These challenges not only affect capacity to deal with natural disasters when they happen but also impede efforts to make climate change relevant to local people (Chem and Kim 2014).

5.2.2 Stung Pursat catchment, Pursat province

Natural disasters have been reported in Pursat province since 1958, but have become more frequent in the last decade. These are typically in the form of floods, drought, livestock diseases, thunderstorms, insect invasion and dengue epidemics. Flood and drought are the most frequent natural disasters that hit the province and cause the most damage, significantly in 1996, 2000, 2001, 2003, 2013 and 2014. Storms in 2000-01 reportedly destroyed 200 ha of rice in Pramaoy commune and, in 2014, demolished nine houses (Chem and Kim 2014).

Kandieng is the district most vulnerable to annual flooding, both flash floods and seasonal inundation by the Tonle Sap Lake. Bakan is also one of the districts most affected by floods, which account for 67 percent of natural disasters in the province (Chem and Kim 2014).

Figure 5.2: Types and severity of natural disasters in Pursat



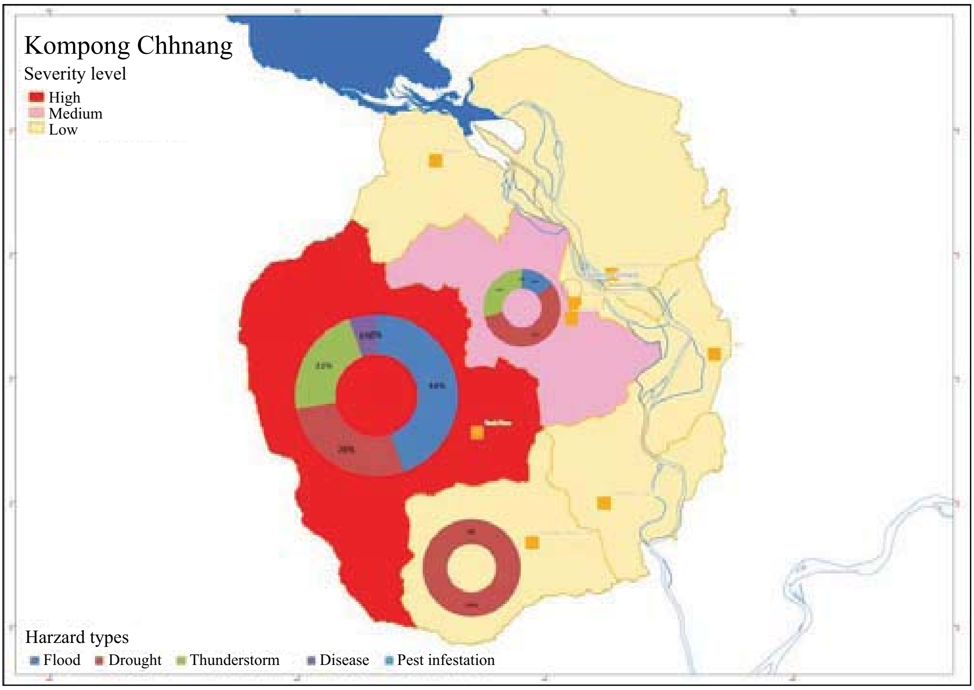
Source: Provincial workshop, 2014

Rapid population growth in Stung Pursat catchment has resulted in high sensitivity to pressures, especially in Bakan district. Poverty is also a problem. Several organisations are involved in disaster management such as the national and local disaster management committees, fisheries communities and farmer water user communities (FWUCs), and 30 safe places have been identified for flood evacuation. However, limited funding and human resources, and lack of cooperative spirit and group solidarity, constrain effective coordination among disaster response agencies (consultation meeting with local leaders in Pursat province, 2014).

5.2.3 Stung Chrey Bak catchment, Kompong Chhnang province

Stung Chrey Bak catchment is affected by flooding, drought, lightning strikes, dengue epidemics, livestock diseases and thunderstorms. Similar to Kompong Thom and Pursat provinces, Kompong Chhnang province is mainly affected by flood and drought.

Figure 5.3: Types and severity of natural disasters in Kompong Chhnang



Source: Provincial workshop, 2014

Sensitivity in Stung Chrey Bak catchment is high due to rapid population growth and poverty. Increasing population pressure has led to overexploitation of natural resources—land, water and forest products. Local communities and authorities reported ecosystem degradation and forest loss. Widespread deforestation caused by local subsistence activities and land concession plantations in natural forest, national parkland and protected areas is causing soil erosion, water depletion and excessive water runoff (Chem and Kim 2014).

As in Kompong Thom and Pursat provinces, FWUCs in Kompong Chhnang province are responsible for managing and maintaining irrigation infrastructure and allocating water. But, with weak capacity and limited financial resources, FWUCs have not been as successful as they could have been (Chem and Kim 2014).

5.3 Participatory assessment of local vulnerability

The study team conducted a participatory climate vulnerability assessment of local community perceptions of vulnerability and sensitivity (site- and context-specific) and broader governance issues. This approach is consistent with the primary project objective to improve local communities' adaptive capacity to climate change. It also meets the project scope, which is to inform decision-making through constructive engagement and evidence-based advocacy and to promote responsive, inclusive and equitable governance.

Participatory V&A assessment is a bottom-up approach for identifying appropriate solutions to reduce hazards or risks caused by climate change (UKaid 2011; McNamara and Limalevu 2011). Used as an entry point for community-based action, it places community knowledge, experiences and attitudes towards climate change at the centre of V&A capacity assessments and in designing locally specific adaptation strategies (Kim et al. 2014).

Two main research questions were defined:

- To what level has climate change affected the vulnerability of male and female water users?
- How do these vulnerabilities vary over time and across topographical zones?

Empirical evidence on perceived vulnerability was collected, analysed and triangulated with secondary data from program plans across a range of adaptation measures for risk reduction, food security, poverty reduction and sustainable livelihoods.

5.3.1 Sampling and fieldwork

A mixed quantitative-qualitative participatory methodology was used. This included household surveys, focus group discussions, in-depth interviews and validation workshops. Data was collected in two stages.

In the first stage, 907 households living in the three study catchments—Chrey Bak, Pursat and Chinit—were purposively and randomly selected for in-depth interviews. Household and village situations made it impossible to achieve equal representations of gender and topography. To validate quantitative data, six focus group discussions were organised in each of the three catchments (one per commune). For each session, five to eight villagers were randomly invited to participate in a two-hour discussion; using guiding questions, information was collected on perceptions of natural resources, access to water and socioeconomic status.

In the second stage, 900 households from the same villages were also purposively and randomly selected. Information was collected on local knowledge of climate change and disaster risk, and perceived sensitivity and adaptive capacity.

Table 5.1: Sample size by catchment, location and gender of household head

Catchment	Total		Upstream		Downstream		Male		Female	
	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2
Chrey Bak	304	300	244	239	62	61	244	222	82	78
Chinit	304	300	183	182	118	118	253	248	48	52
Pursat	299	300	219	223	81	77	239	250	61	50

All completed and reviewed questionnaires were input into a database, and then descriptive and inferential statistical analyses were conducted. A vulnerability index was calculated following the method used by Piya et al. (2012) in their study on Nepal. Since the specific contexts differ, some indicators within each component were modified. (Calculation of the indices and vulnerability index is presented in Annex 5.1.)

5.4 Findings and discussion

5.4.1 Exposure

Exposure is primarily to flooding, drought and storms. Most respondents perceived their exposure to these risks as relatively high, the majority observing that drought and flood are the most frequent hazards and more destructive than 10 years ago.

5.4.1.1 Flood and drought

Generally, around half of the respondents observed that floods (41 percent) and drought (55 percent) are happening more often (Figure 5.4). Respondents had experienced more damage from drought than from flood. This perception may have been driven by two factors: paddy rice can fully or partially recover from a normal and short inundation (7 to 10 days), whereas crops are often completely destroyed by drought.

As Figure 5.5 shows, 48 percent of respondents downstream from National Roads 5 and 6 and 38 percent of those living upstream perceived that floods are becoming more common. However, 40 percent of respondents in upstream villages felt that floods are less frequent than before. High percentages of local people perceived a high frequency of drought events: 58 percent of respondents living upstream and 48 percent of those downstream thought that drought had become more frequent.

These findings confirm the observed topographic and climatic conditions. People living on the floodplain or in flood-prone areas have observed annual flooding events, while those in the upper catchment have experienced more frequent flash floods due to changes in rainfall intensity and in forest cover.

Figure 5.4: Local perceptions of flood and drought frequency in the last 10 years

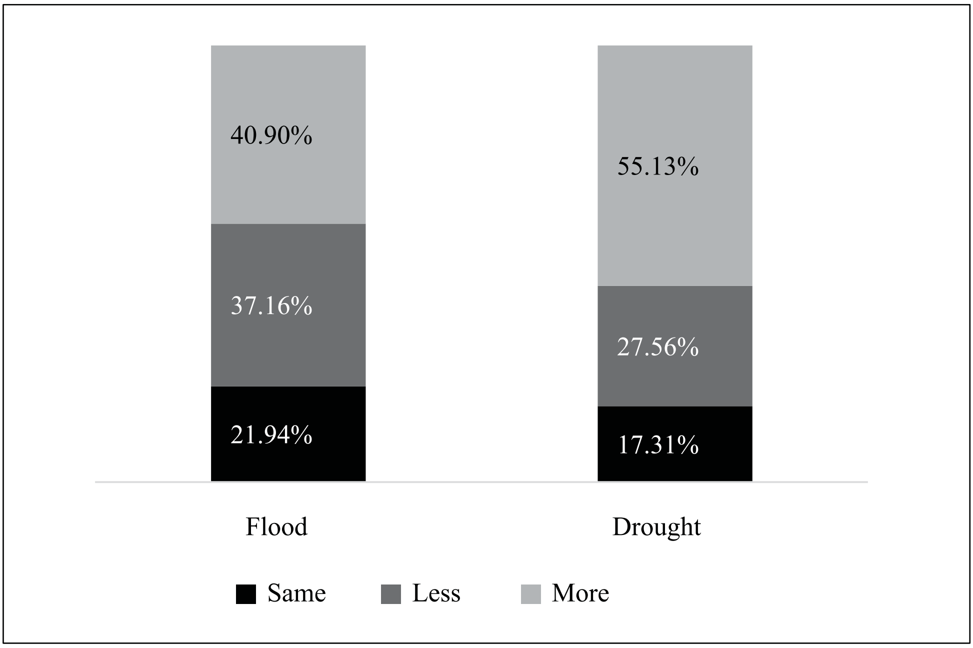
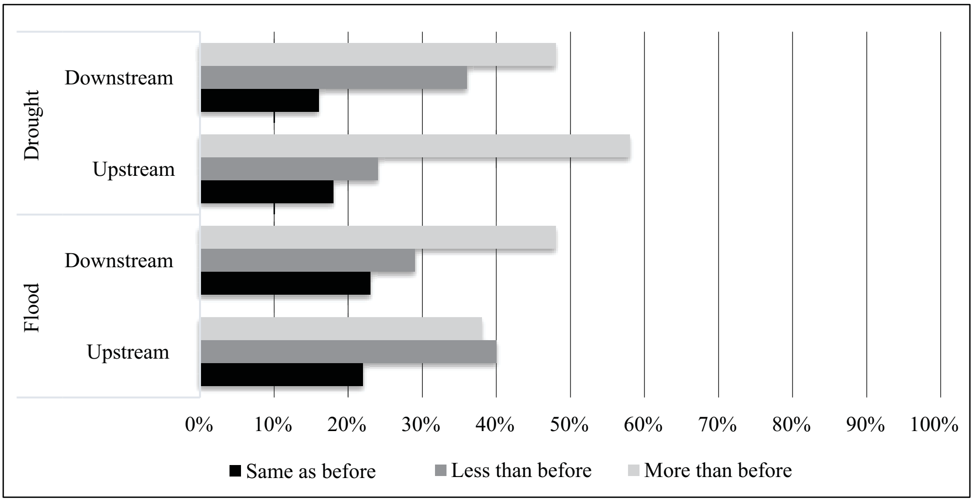


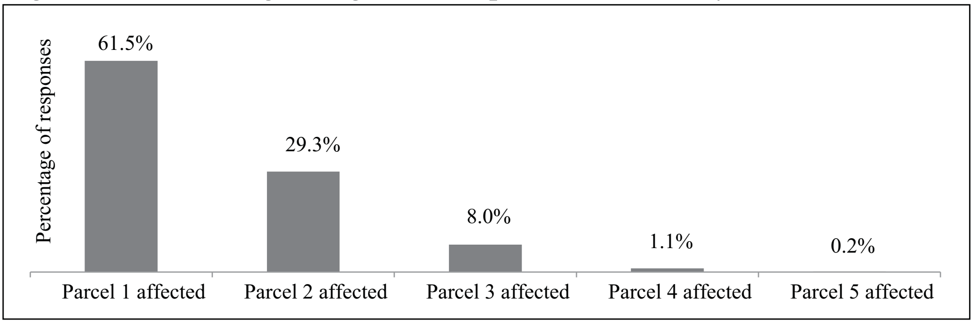
Figure 5.5: Perceptions of local people on flood frequency



5.4.1.2 Affected farms

With respect to household landholdings, 174 have land parcels in the range of 10,001 to 15,000 m^2, and 124 have 5001 to 10,000 m^2. Of the 907 households interviewed, 902 (99.4 percent) own land and only five (0.6 percent) do not. Regarding rice fields, 136 households (nearly 15 percent) do not have a rice field, and 242 have less than 1 ha of rice field. This implies that most households have land parcels totalling about 0.5 to 2.5 ha for living and cultivating crops. They own more than one parcel of land, and each parcel is usually in a different location. Nearly 62 percent of respondents reported having one parcel of farmland affected by a natural disaster, and a few reported having four or even five parcels of land affected (Figure 5.6). More than 80 percent of land parcels are used for growing rice.

Figure 5.6: Percentage of agricultural parcels affected by a natural disaster



5.4.1.3 Exposure index

Calculation of an exposure index in which only the number of reported natural disasters was considered reveals that floods contribute the most to exposure level. Among the three catchments, Chinit seems to have been exposed the most to natural disasters. Drought, however, is not a major problem in Chinit catchment, especially around the reservoirs and in the irrigation command area. Overall, thunderstorms contribute the most to increasing the exposure index, followed by floods and drought. Drought has a negative sign, meaning in comparison to other disasters, drought contributes the least to increasing the exposure index.

Table 5.2: Weights and average natural disaster frequency in the last 50 years

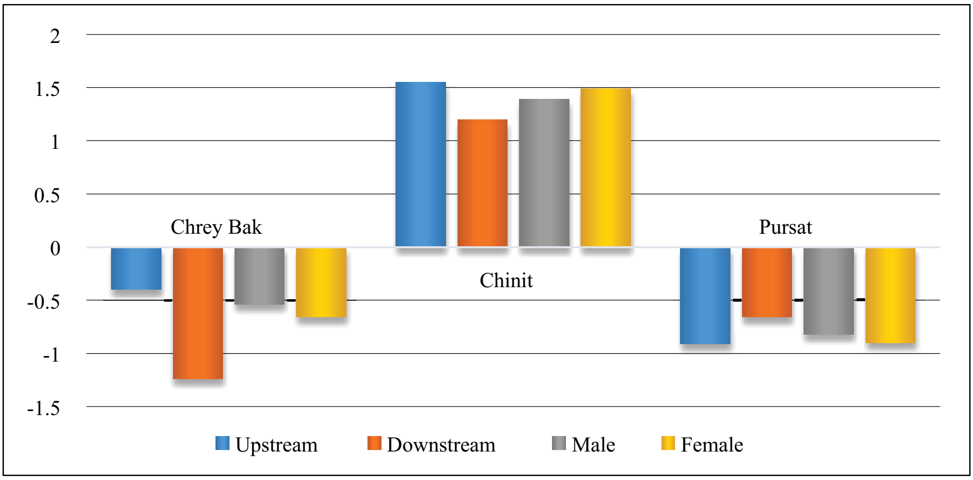
Natural disasters	Weight	Chrey Bak	Chinit	Pursat
Flood	0.42	4.50	5.33	4.67
Drought	-0.46	4.50	0.67	2.00
Thunderstorms	0.78	3.00	5.67	0.00

Note: Weight represents the relative importance of a given variable on a scale of minus 1 to plus 1, where minus 1 = least important and plus 1 = most important.
Source: Provincial workshops in Kompong Chhnang, Kompong Thom and Pursat, 2014

Geographically, those in Chrey Bak and Chinit catchments are more vulnerable than those living downstream in Pursat catchment. By gender, in both Pursat and Chrey Bak catchments, male household heads are more exposed than female household heads to climate risk (Figure 5.7).

People think that these extreme events are going to increase in frequency and magnitude: those in the downstream reaches have observed more flooding while those in upstream areas have observed more droughts.

Figure 5.7: Exposure index by location and household head gender



5.4.2 Sensitivity

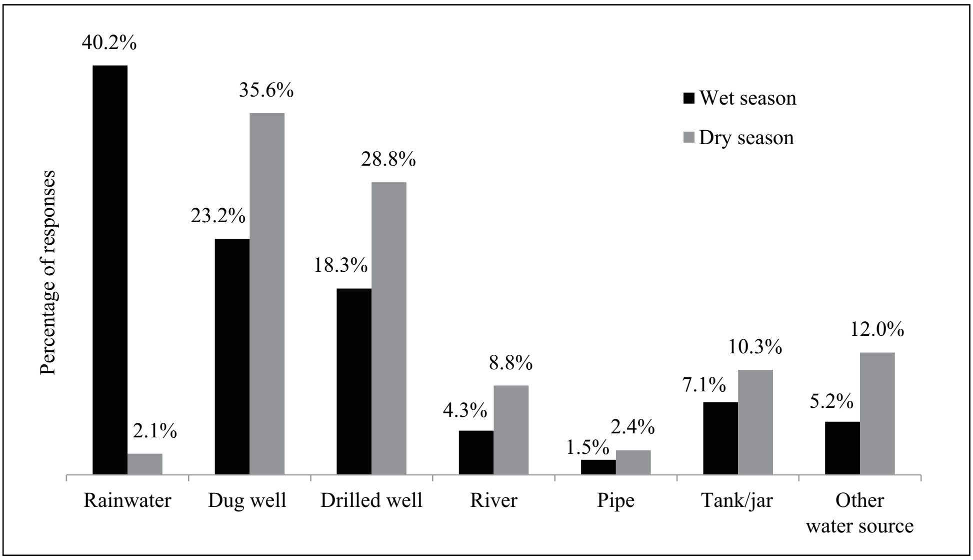
The effects of current and future exposures to natural hazards on vulnerable systems depend on the sensitivity and adaptive capacity of the system. Sensitivity to a climate hazard is understood as the degree to which a system responds to a change in climate conditions, depending on ecosystem productivity and functioning, and distance from important natural resources such as water and facilities such as flood havens.

5.4.2.1 Water resources

Water for domestic use

The majority of rural households depend on rainwater and groundwater as the main sources of supply. About 40 percent of local people use rainwater in the wet season for domestic purposes, and 23 percent (36 percent in the dry season) use water from dug wells and 18 percent (29 percent in the dry season) from tube wells. Only very small numbers of households (1.5 percent in the wet season and 2.4 percent in the dry season) are able to connect to tap (running) water.

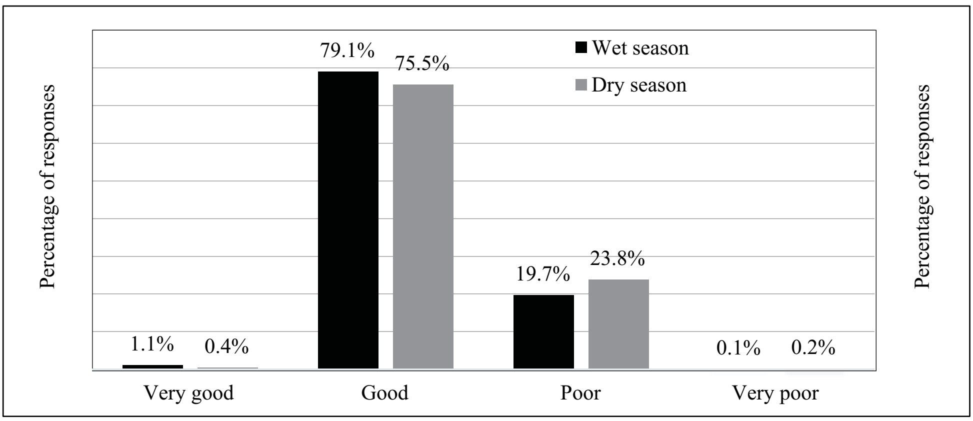
Figure 5.8: Water sources for domestic consumption



Only 38.7 percent of all respondents face water shortages for domestic use. They have either bought water or paid to have it transported to their homes. Two-fifths (107 of 249) of households reported spending up to 10,000 riels/month on water in the dry season, and half of them (55 of 106) spend up to 10,000 riels/month in the wet season.

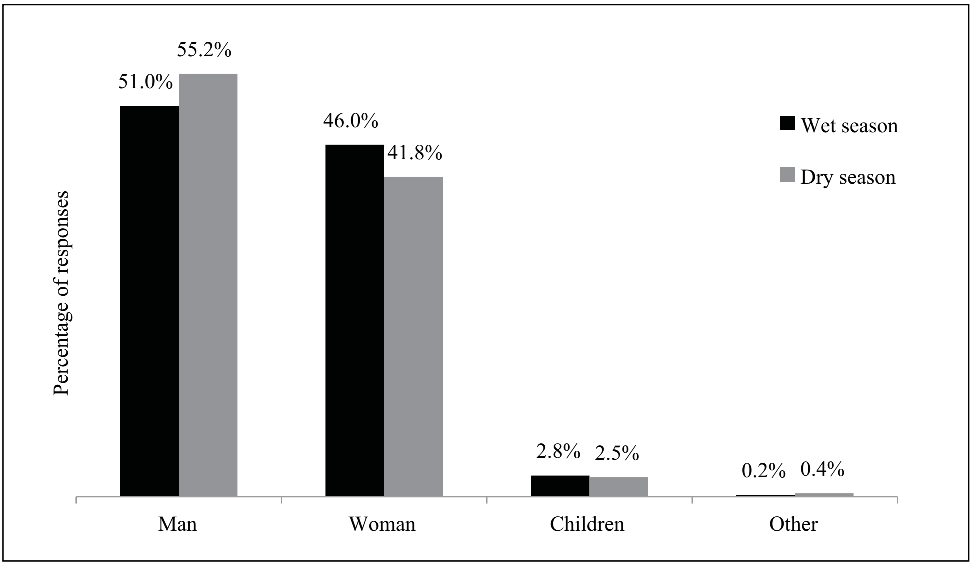
A large majority of respondents said water quality was good in both seasons. However, around one-fifth said quality was poor and therefore have to boil or filter their drinking water.

Figure 5.9: Responses on domestic water quality



Men bear the gender burden of water collection for domestic consumption, though women's share of this burden is substantial (46 percent in the wet season and 42 percent in the dry season) (Figure 5.10). About 3 percent of children also help in collecting water.

Figure 5.10: Water collectors for domestic consumption



Summing up, more than 61 percent of respondents do not have a problem accessing water for domestic consumption while nearly 39 percent do. This indicates that access to drinking water in the study catchments is higher than the national rural average of 44.5 percent NSDP 2014-18 (RGC 2014). But there are problems with access to improved water sources: less than 2 percent have access to running water, and many have to fetch water from sources of doubtful quality. Nearly 50 percent of those who have water problems filter or boil their drinking water, more than 22 percent planned to dig or drill a new well (but without properly checking groundwater quality) and nearly 14 percent planned to install a water tank or jar.

Growing dependence on groundwater and groundwater overuse can catalyse water quality problems, especially arsenic contamination. Groundwater in some locations in the study catchments already has medium to elevated levels of arsenic contamination (MOWRAM 2013).

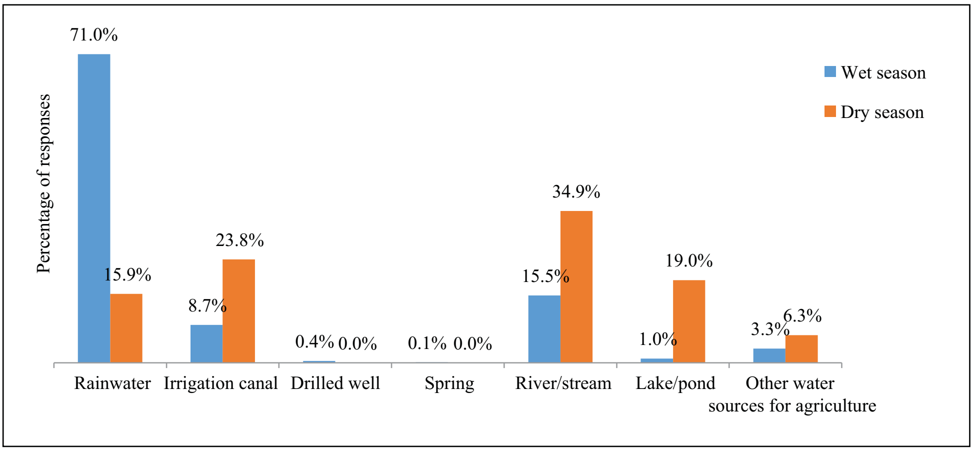
Water for agriculture

In Cambodia, agriculture, especially rice production (representing about 85 percent of total farm production), accounts for about 9330 MCM, or 90 percent of total water use (MOWRAM 2013).

Analysis of irrigation in all three catchments shows a high dependence on rainwater and river water. River levels fluctuate greatly with the season. Proper water storage facilities are lacking and regulation for water supply systems is largely absent (see Chapters 2-4).

Farmers use different sources of water supply depending on the season. In the wet season 71 percent of farmers rely on direct rainfall to water their crops, nearly 16 percent get water from a natural stream and almost 9 percent use water from an irrigation canal (Figure 5.11). In the dry season, the largest share of farmers, nearly 35 percent, use river water for irrigation, followed by nearly 24 percent who use water from an irrigation canal, and about 19 percent use pond and lake water.

Figure 5.11: Water sources for irrigating farms

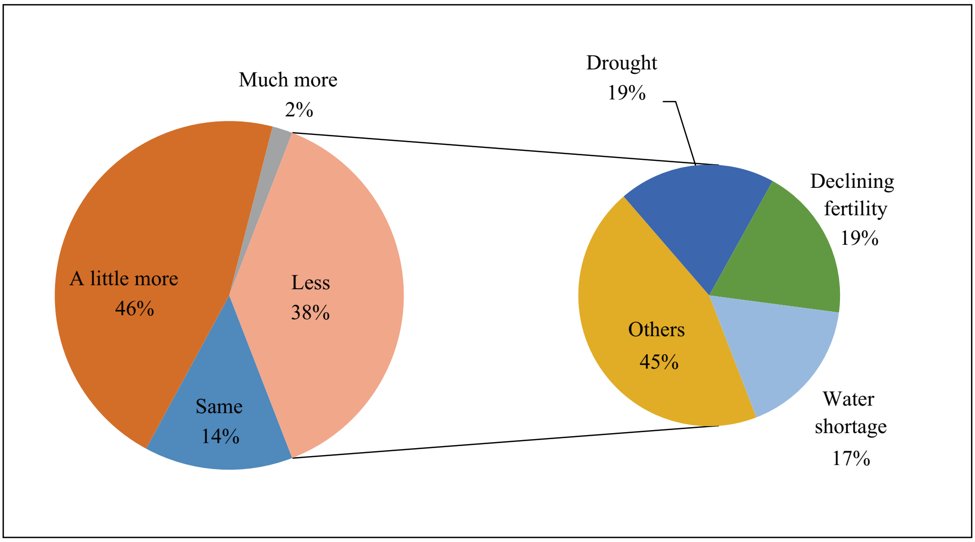


Nearly 81 percent of respondents said that the primary water problem in their farming is either flood or drought or both flood and drought. The other 19 percent reported having no problems regarding water. About 15 percent of those living downstream and 21 percent of those upstream have enough water to meet agricultural needs.

5.4.2.2 Crop productivity

Forty-six percent of the respondents working in agriculture perceived production to be a little higher than 10 years ago, while 38 percent thought it was lower. Most respondents were worried that lower crop production would affect their food security and income. Figure 5.12 illustrates the main problems that reduce crop yields.

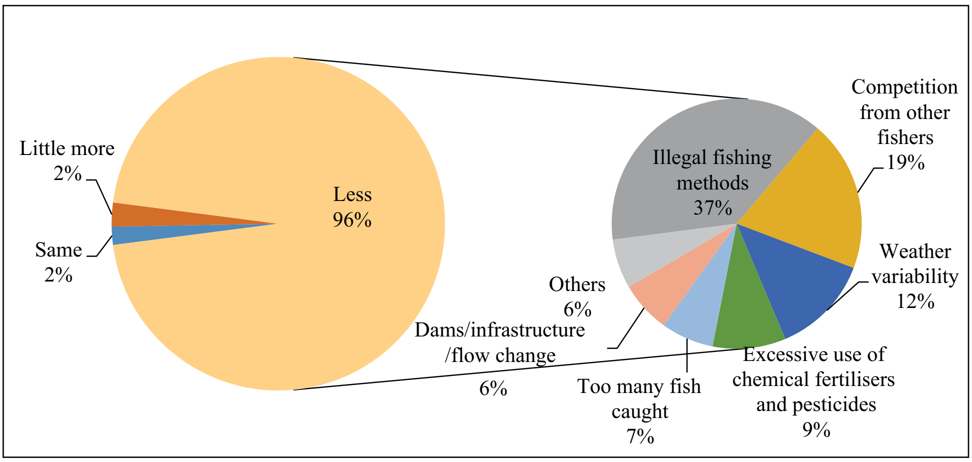
Figure 5.12: Perceptions of crop production in the last 10 years



5.4.2.3 Fisheries and animal aquatic resources

Half of the respondents said that they have gathered aquatic resources (crabs, frogs, snails and shrimp) and caught fish from the surrounding natural ecosystems, which are considered to be the most important sources of food after rice. Nearly 96 percent of them said that fish and other aquatic resources are less per fishing effort today than 10 years ago. They put this down to the growing number of fishers and declining quality of fish. As Figure 5.13 shows, the largest reported cause of decreased aquatic resources is illegal fishing practices. Climate change and weather variability are also believed to contribute to resource depletion. High dependence on, and loss of, living aquatic resources leads to a corresponding high level of community sensitivity.

Figure 5.13: Perceptions of the state of fish and aquatic resources in the last 10 years



5.4.2.4 Sensitivity index

Based on the calculation of the sensitivity index, the indicator that increases sensitivity to climate risks the most is the share of natural resource-based income sources (composed of farming, fisheries and forestry incomes) in household income. The second biggest contributing factor is the area of land affected by disasters, followed by the area of crops affected. The indicators that reduce the level of sensitivity include the number of fatalities caused by disasters or weather hazards, and the share of wages in household income.

Table 5.3: Mean values and weights and for sensitivity indicators in the last 50 years

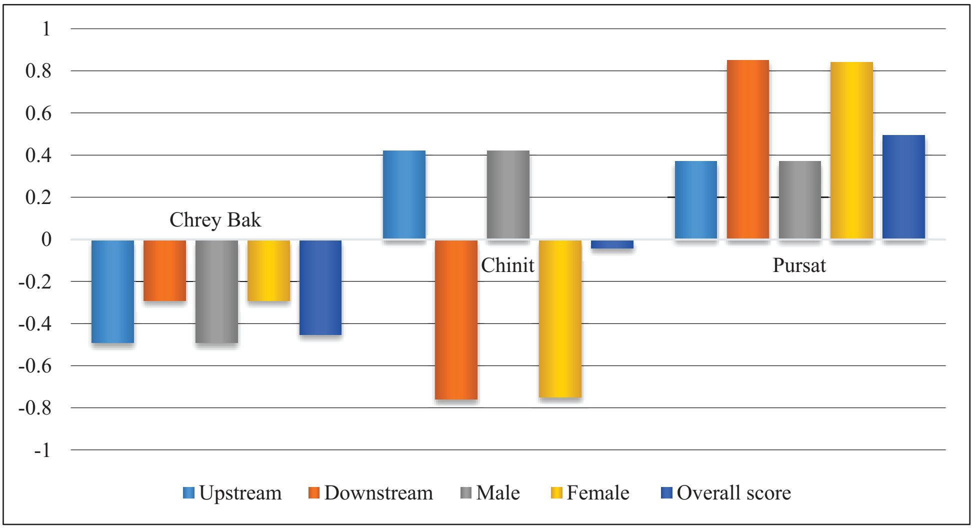
Indicators	Weight	Aggregate	Chrey Bak	Chinit	Pursat
Fatalities (number)	-0.01	0.012	0.01	0.01	0.03
Land affected (ha)	0.20	1.09	0.45	1.14	1.68
Livestock affected (head)	0.03	3.33	2.79	4.24	2.97
Crops affected (ha)	0.10	0.76	0.68	0.69	0.90
% of natural resource income in HH income	0.69	46.14	36.41	44.94	57.07
% of wages in HH income	-0.69	53.86	63.59	55.06	42.93

Source: Field survey, February 2015

The overall sensitivity score for each catchment is shown in Figure 5.14. Pursat is the most sensitive. It has the highest fatality rate, the largest areas of land and crops affected, the biggest share of natural resource-based income and the lowest share of wages. People living downstream in Pursat and Chrey Bak catchments are more sensitive than those living in the upper catchment because they face more frequent floods and droughts.

In Chinit catchment, people living upstream are more sensitive than those in the downstream reaches because they depend more on natural resources. Female household heads are more sensitive than male household heads in Chrey Bak and Pursat catchments because they have lost relatively more agricultural produce to disasters. In Chinit catchment, the situation is reversed. There, although male household heads depend on natural resource-based income more than female household heads do, they have suffered fewer agricultural losses thus lowering their overall sensitivity index score.

Figure 5.14: Overall sensitivity index, by location and household head gender



5.5 Adaptive capacity

5.5.1 Overview

Adaptive capacity means the ability to cope with and adjust to the impacts of a hazard and recover (MOE 2013). The capacity to cope and adapt is determined by a range of socioeconomic, institutional and political factors, including accessible assets and resources (natural, economic, social), wealth, power and influence, and where people reside and draw their resources, as well as how risks are perceived and interpreted and willingness to adapt (MOE and UNDP 2011). Governance and access to political assets are discussed in Chapters 6 and 7. This section focuses on access to social and economic wealth, natural resources, climate risk perception and willingness to adapt.

Among the five assets portrayed in Table 5.4, human assets have the greatest influence in enhancing adaptive capacity to climate change, disasters and crises. Among human assets, the most influential indicator is education level. Training, on the other hand, is the least influential; the negative dependency ratio shows that it decreases adaptive capacity. Following human assets are physical assets, of which a disaster-proof house has the most influence on adaptive capacity. Access to a mobile phone and radio also increases adaptive capacity since people can receive early warnings and other disaster information about extreme events; land with a water supply is the least influential indicator in this category. Natural assets have the least influence in improving adaptive capacity.

Table 5.4: Aggregate adaptive capacity index, composite subindices and component indicators

Physical assets (0.55)	Type of house	(0.42)
	Mobile phone and radio	(0.39)
	Land with water supply	(0.21)
Human assets (0.59)	Education	(0.47)
	Dependency ratio	(-0.03)
	Training	(0.28)
Natural assets (0.07)	Less productive land	(-0.12)
	Natural water source supply	(0.04)
Financial assets (0.51)	Household annual income	(0.39)
	Livestock standard unit	(0.33)
	Savings	(0.022)
Social assets (0.27)	Membership in CBOs	(0.10)
	Access to credit	(0.18)

Note: Figures in parentheses are the loadings obtained from the first principal component and taken as weights for the respective indicators (bi).

Table 5.5 describes the values of adaptive capacity of each of the five assets by catchment. For the first indicator, a disaster-proof house, people in Chinit catchment possess this asset the most. All the indicators of the three catchments are similar, except for household annual income and household savings. People from Chinit have the highest income. This might be due to diversified livelihoods; besides farming, people there can collect timber and non-timber forest products. People from Chrey Bak catchment, have the highest amount of savings.

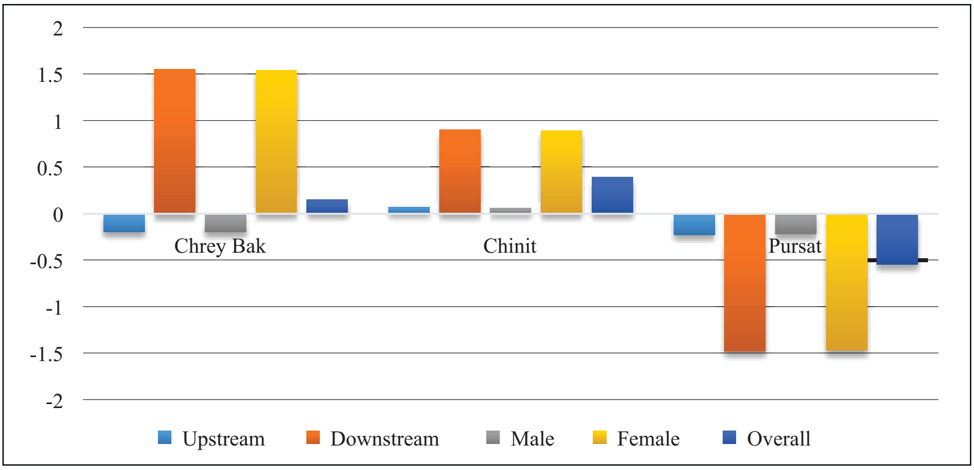
Overall adaptive capacity in Chinit catchment is the highest due to higher gross household incomes (Figure 5.15). The adaptive capacity of those living downstream in Chrey Bak and Chinit catchments is higher than that of people upstream; this is because they have more of all five assets than those in the upstream reaches. In Pursat catchment, people living upstream have higher adaptive capacity than those in downstream areas; this is because people in upstream areas own more physical, natural, financial and social assets. The adaptive capacity in each catchment by location is statistically significant at the 1 and 5 percent levels (Table A1, Annex 5.1).

Table 5.5: Mean values for indicators of adaptive capacity

Indicators	Aggregate	Chrey Bak	Chinit	Pursat	P-value
Physical					
House type (mean)	2.30	2.25	2.54	2.10	0.00***
Possess device to access information (mobile, radio)	0.92	0.95	0.94	0.87	0.00***
Land with sufficient water supply	53.79	68.57	57.61	34.82	0.00***
Human					
Highest qualification in the family	7.39	7.50	7.56	7.12	0.220
Dependency ratio	2.15	1.99	2.21	2.24	0.07*
Training or vocational course attended by family member	2.15	1.99	2.21	2.24	0.07*
Natural					
Share of own less productive land (%)	53.92	67.26	50.24	43.92	0.00***
Natural water source supply	0.47	0.43	0.48	0.49	
Financial					
Gross household annual income (10,000 riels)	1010.81	794.65	1145.14	1092.66	0.00***
Livelihood diversification index	3.29	3.44	3.07	3.37	0.598
Total household savings	1.83	2.98	0.57	1.94	0.262
Social					
Membership in CBO	0.38	0.53	0.26	0.35	0.00***
Access to credit (1=yes, 0=no)	0.92	0.97	0.95	0.85	0.00***

Note: Significant at ***1%, **5% and *10%.
Source: Field survey, February 2015

Figure 5.15: Adaptive capacity overall and by location and household head gender

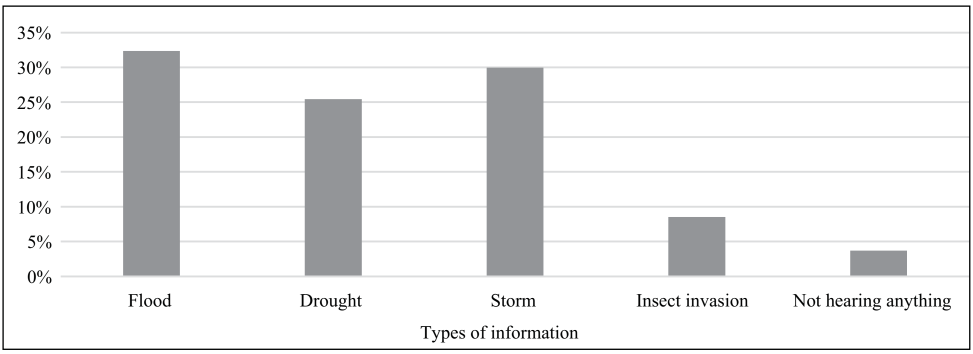


Female household heads in Chrey Bak and Chinit have higher adaptive capacity than male household heads. This result is not statistically significant, however. In Pursat, male household heads have a statistically significant higher adaptive capacity than female household heads; this is because they can access more resources (Table A2, Annex 5.1).

5.5.2 Access to information and early warnings

Access to information, especially to early warnings, long-term and medium-term flood and drought projections and agricultural and other income generation options and practices, is considered a key element for improving adaptive capacity and climate resilience.

Figure 5.16: Access to disaster information



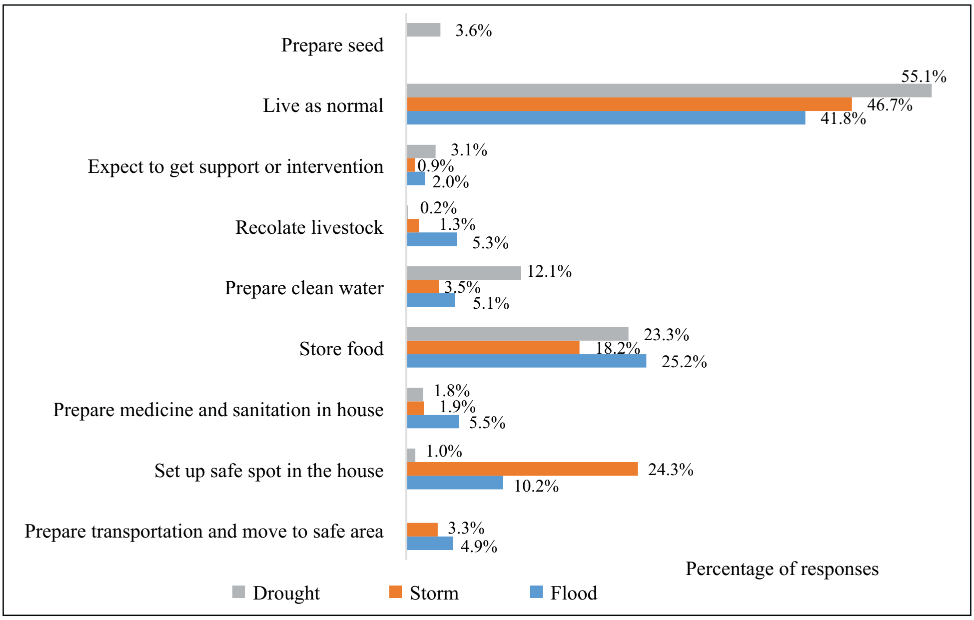
One-fourth of all respondents said they had received flood, storm or drought warnings. Of those, 56.23 percent got information from the radio and 50.06 percent from television. Another information channel was word of mouth, which accounted for 39.14 percent. Local authorities also played a role in sharing information (8.71 percent).

5.5.3 Perception and willingness to change

5.5.3.1 Responses to change

Around half of all respondents said they did not prepare anything at all to cope with flood, storm and drought, while only around 20 percent stored food to cope with those disasters.

Figure 5.17: Preparation for disasters



Most respondents have not adjusted their farming practices or changed their crops to adapt to weather variability or climate change: 93 percent of rice and crop farmers had not switched to other crops or cropping patterns, due to habit and water constraints. Many who had not changed their crops despite flood and drought damage said they did not have the experience or expertise to select and grow different crops. They claimed they did not have enough information and knowledge on what crops they could change to.

More downstream (20 percent) than upstream farmers (5 percent) have changed their crops due to flood, as flooding occurs more often in downstream areas. Similarly, more upstream farmers than downstream farmers have changed their crops due to drought, because drought is more frequent upstream. However, it is safe to assume that both upstream and downstream farmers would be willing to practice climate-resilient cropping or grow less water-intensive crops if they understood the impacts and implications of climate variability and change, or gained more confidence in their ability to improve their family well-being and access funding opportunities.

Figure 5.18: Changes in responding to climate change

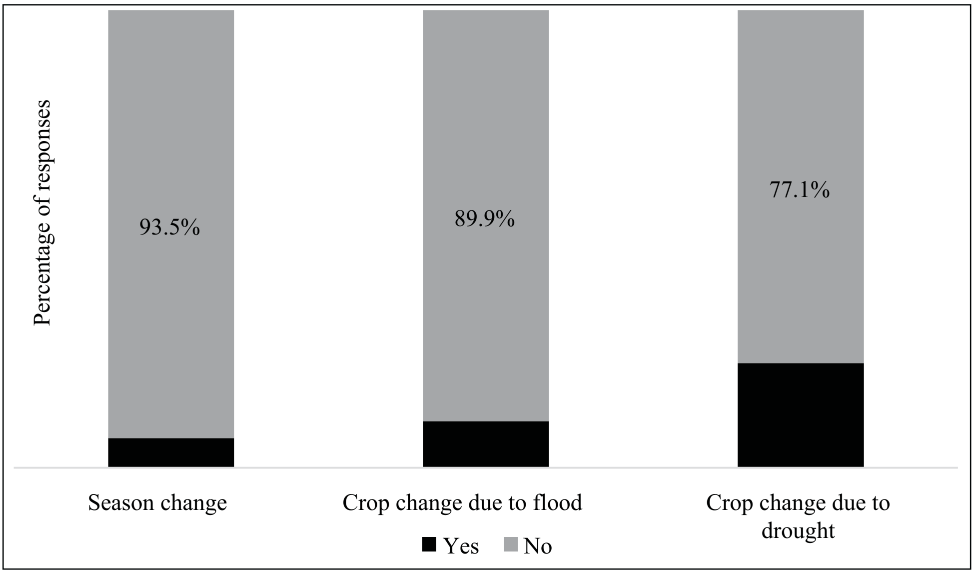
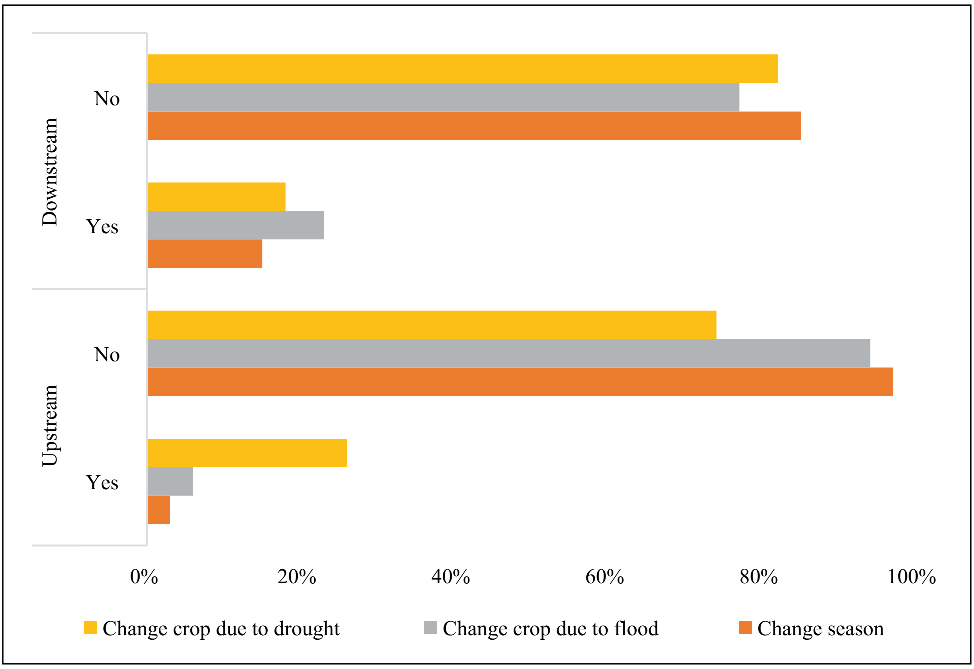


Figure 5.19: Changes in cultivation season and crop selection due to flood or drought



5.5.3.2 Prevalent forms of adaptation or recovery

The assessment found that the population mostly responded to disaster risks reactively and autonomously rather than according to planning based on scientific information. Respondents were also asked what they would do if they could not farm, fish or collect forest products because of natural disasters. The answer "not sure" ranked top.

Table 5.6 reflects how local options are constrained by limited alternative livelihood initiatives. Respondents ranked "borrowing money" and "depending on help from others" as their second and third options, respectively, should their livelihoods be hit by disaster. This suggests a lack of self-help or self-reliance. It can be inferred, therefore, that local people have no alternative livelihoods at all, contributing to their high level of vulnerability.

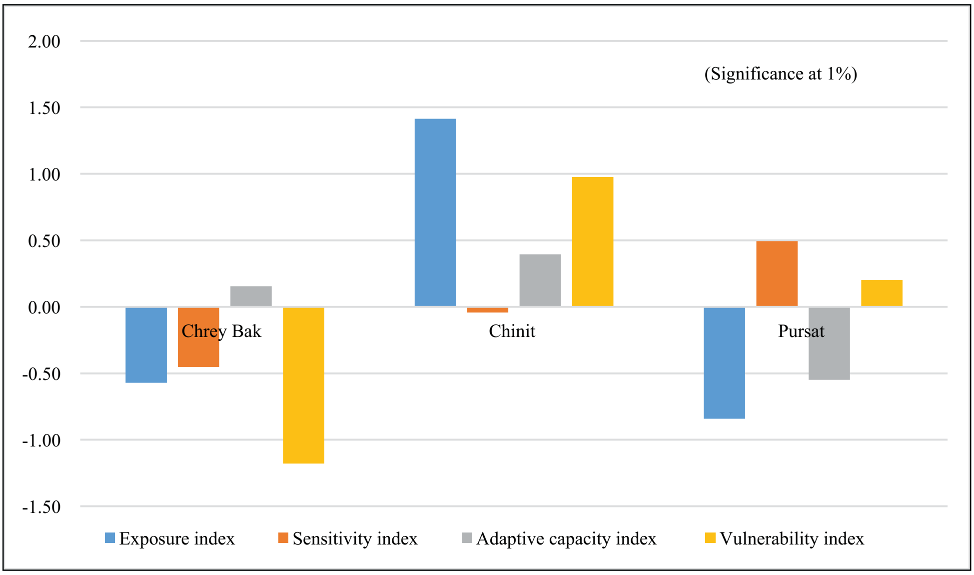
Table 5.6: Ranking of alternative livelihoods if current ones were destroyed by disaster (%)

Livelihood source	1st	2nd	3rd
Shift to another natural resource activity	4.99	0.00	4
Shift to livestock cultivation	5.49	1.28	4
Shift to farming	1.37	1.28	0
Seek employment locally	12.97	10.26	0
Migrate	6.73	15.38	8
Start own business	3.49	9.62	8
Borrow money/food from others	4.74	**37.82**	24
Depend on help from others	2.24	9.62	**44**
Not sure	**40.40**	5.13	0
Other	17.58	9.62	8
	100	100	100

5.5.4 Vulnerability

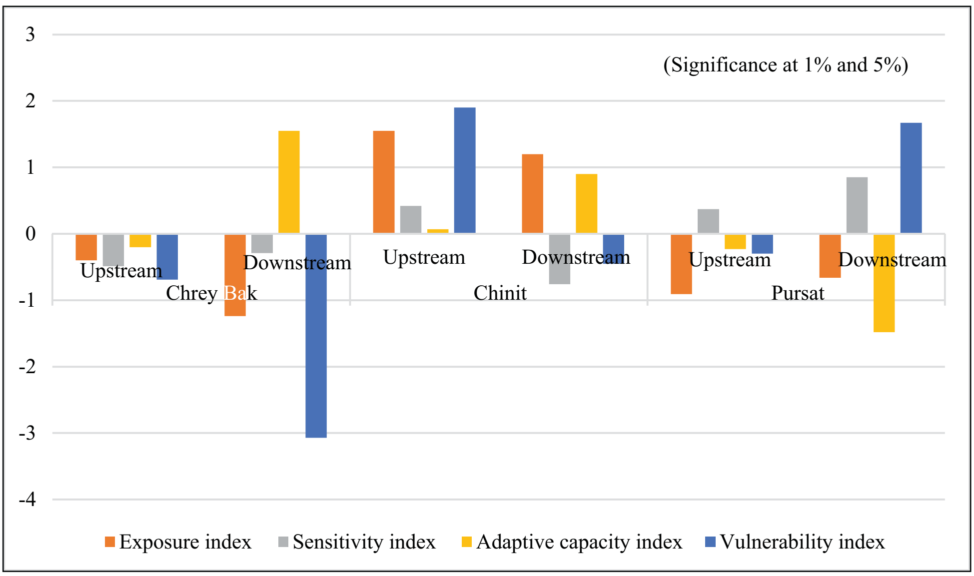
The calculation of a vulnerability index reveals that Chinit catchment is the most vulnerable and Chrey Bak the least vulnerable (Figure 5.20). A statistical test showed this to be significant at the 1 percent level (Table A3, Annex 5.1). The vulnerability index, however, does not take into account predicted future impacts of climate change. Chinit catchment has the highest level of exposure. And although it has the highest level of adaptive capacity, when the three components are combined, Chinit turns out to be the most vulnerable. A final assessment of vulnerability, which considers predicted future changes in climate under various scenarios, is presented in Chapter 8.

Figure 5.20: Index scores for vulnerability in the three catchments



Vulnerability levels differ significantly among the catchments. In Chrey Bak, those living upstream are more vulnerable than those downstream (Figure 5.21). Although the level of exposure is lower upstream, low adaptive capacity creates higher vulnerability. This result is statistically significant at the 1 percent level (Table A4, Annex 5.2). In Chinit catchment, due to high exposure and sensitivity, people in upstream areas are also more vulnerable than those downstream. In Pursat catchment, because of high sensitivity, downstream reaches are more vulnerable than upstream parts.

Figure 5.21: Index scores for vulnerability, by location



5.6 Conclusion

This assessment of climate change vulnerability was conducted in Stung Chrey Bak, Stung Pursat and Stung Chinit, applying participatory assessment tools. It finds that local people in the three catchments have relatively low to moderate adaptive capacity in terms of income, access to early warnings and disaster preparedness, willingness to respond to changes and choice of alternative livelihoods. They have high sensitivity to water availability and uses for domestic consumption and farming, dependence on fish and other living aquatic resources, and health problems related to water quality and climate. They have high exposure to frequent floods and droughts and the effects of those on farms and rice fields. It can therefore be concluded that people in the three catchments are highly vulnerable to the impacts of climate change.

Efforts to build adaptive capacity should pay greater attention to natural and social assets which have been neglected in the field of disaster management. These two assets play a prominent role in helping people cope with stresses but they are the least common among the five assets explored in this study. Land quality and natural water sources should be properly managed to ensure their sustainability. Social assets including access to credit, seed banks and community-based organisations should be built up and expanded. Overall, due to their higher incomes, the adaptive capacity of people in Chinit catchment was the highest.

Adaptation responses to extreme weather, flood and drought are limited; most respondents said they intended to continue “living as normal” and “not change their crops”. There is an urgent need to equip farm households with the knowledge, skills and means required for adaptation and mitigation responses. Moreover, the reach of early warning systems seems limited. Mobile phone messaging is a convenient way to reach the most people because mobile usage is widespread.

Chinit catchment, despite having the highest adaptive capacity, also has the highest level of exposure and is highly sensitive. When the three components are combined, Chinit is the most vulnerable. Although Chrey Bak is the least vulnerable catchment, it is still vulnerable because of high dependence on climate-sensitive resources including water, land and ecosystem services and limited local knowledge about climate change and how to deal with its impacts.

People living upstream in Chinit and Chrey Bak catchments are more vulnerable than those living downstream. Upstream, the frequent occurrence of extreme events such as drought and mountain floods, and low adaptive capacity, heighten vulnerability. People downstream are more susceptible to river and flash floods in the rainy season and drought in the dry season than people upstream. However, downstream communities, especially near Tonle Sap Lake, have higher adaptive capacity and have adapted better to climatic stress by changing their cropping patterns and crops; they are also closer to roads, communication and health facilities, and schools.

It is a surprise that female household heads, due to a higher adaptive capacity, are slightly less vulnerable than male household heads in both Chrey Bak and Chinit catchments. Even so, adaptive capacity has to be improved in order to cope with the uncertainty of change. Among the three catchments, greater attention should be paid to the situation of female household heads in Pursat catchment.

5.7 Suggested ways forward

This study serves as a baseline for assessing the vulnerability of local people to climate change impacts. A follow-up study in the same locations using the same sample size would complement and consolidate the study findings. The resulting panel data would enhance our understanding of vulnerability over time.

Future V&A assessments should use simple but tangible indicators so that the multidimensional aspects of community vulnerability are measured in a comprehensive and robust way.

Ensuring water security for agriculture is vital, as water supplies are already insufficient to meet demand. This problem will be made worse by climate change. Irrigation structures, reservoirs, community and household ponds, as well as storage capacity in lakes and wetlands, should be developed to mitigate potential water shortages.

Livelihood diversification into off-farm jobs, different farming practices such as multicropping, and other sources of income such as multi-purpose farming should be supported to reduce dependence on climate-sensitive resources, thus improving adaptive capacity and reducing vulnerability.

Adaptation responses to extreme events should be disseminated so that people know how to prepare for a disaster and how they can reduce their vulnerability. Strategies should be specific, simple and applicable, and promote modern crop varieties that have market value and are more flood or drought tolerant.

Early warning systems should target and support the response strategies of vulnerable groups. Mobile phone usage is widespread in all three catchments, making it feasible to send alerts about impending disasters through mobile networks. This would be more effective if messages were sent in Khmer rather than English.

Increasing household access to assets that are vital for climate change adaptation should be given greater attention. Better access to natural and social assets would enable people to have more control over their lives and stimulate innovation. Setting up more local community-based organisations is a must. Government institutions, NGOs and development partners also have a role to play. Physical and human assets also need to be improved.

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Annex 5.1: Calculation of Vulnerability Indicators

Vulnerability is a multidimensional and complex interrelationship of multiple factors. In order to measure the vulnerability of a community, all variables related to the components must be converted to indices. Vulnerability, based on the definition of IPCC (2001), is a function of exposure, sensitivity and adaptive capacity. Exposure refers to the nature and degree that a community is exposed to climatic variations. Sensitivity is the degree that a system is affected, either adversely or beneficially, by climate-related incitements. Adaptive capacity is the capacity of a system to regulate to climate change including climate variability and extremes, to moderate the potential damage from it, to benefit from its opportunities or to cope with its consequences.

Exposure

Exposure is the historical change in climate variables: rate of change in average annual minimum temperature, maximum temperature and precipitation, and extreme climate events (frequency of climate-related natural disasters such as floods, landslides, droughts and hailstorms over the last 10 years). The study used data that spans 50 years (1960-2010) on flood, storm and drought, collected at commune level in the provinces of Kompong Chhnang, Pursat and Kompong Thom.

Table A1: Indicators for exposure

Component indicators	Description of indicators	Unit	Hypthesised relation
Extreme climate events	Frequency of climate related natural disasters - floods over the last 50 years	Number	+
	Frequency of climate related natural disasters - droughts over the last 50 years	Number	+
	Frequency of climate related natural disasters - thunder storms over the last 50 years	Number	+

Sensitivity

Three component indicators were selected for sensitivity measurement: fatalities, damage to property and change in income structure over the last 10 years. Fatalities (death of family members caused by climate disaster) and property damage (land, livestock and crops) represent an increase in sensitivity. The sensitivity of a community increases when households rely heavily on natural-based income from agriculture, livestock and non-timber forest products because those income sources are highly sensitive to climate.

In contrast, sensitivity is reduced for households with a higher share of non-natural income sources such as salaried jobs, remittances and skilled non-farm jobs.

Table A2: Indicators for sensitivity

Component indicators	Description of the indicators	Unit	Hypthesised relation
Fatalities	Death of family member due to climate related disasters (flood, drought, disease) over the last 10 years	Number of family members	+
Damage to property	Total land damaged by flood over the last 10 years	Area in local units (ha)	+
	Total livestock deaths due to flood/drought/disease over the last 10 years	Livestock (head)	+
	Total crop damage due to flood/drought/disease over the last 10 years	%	+
Income structure	Share of natural resource-based income (agriculture, livestock, forest, honey, handicrafts) to total income	%	+
	Share of non-natural-based remunerative income (salaried job, remittance, skilled non-farm job) to total income	%	-

Adaptive capacity

The adaptive capacity component is made-up of five groups of assets: physical, human, natural, financial and social. The selection of indicators for adaptive capacity is based on the DFID sustainable livelihoods framework, whereby adaptive capacity is taken to be a function of household access to or ownership of these assets (Aggarwal et al. 2010). Subcomponents of each asset group are generated from different types of indicators. These indicators measure the positive and adverse effects of access to or ownership of those assets on household adaptive capacity.

Table A3: Indicators for adaptive capacity

Component indicators	Description of the indicators	Unit	Hypothesised relation
Physical assets	House type (mean)	Ordinal value	+
	Have device to access information (mobile, radio)	Ordinal value	+
	Land with sufficient water supply	% of total	+
Human assets	Highest qualification in the family	Number of schooling years	+
	Dependency ratio	Number	-
	Training or vocational coursed attended by family members	% of total	+
Natural assets	Share of less productive land (%) possessed	Ordinal	-
	Natural water sources	Ordinal	+
Financial assets	Gross household annual income	KHR	+
	Livelihood diversification index	Unit	+
	Total household savings	KHR	+
Social assets	Membership in CBO	Number	+
	Access to credit (1=yes, 0=no)	Ordinal value	+

Principal component analysis (PCA)

Following Piya et al. (2012), principal component analysis (PCA), a statistical method, was carried out to define the indices of components and subcomponents of selected indicators. PCA is capable of analysing the interrelationships among large groups of variables by minimising loss of information. Moreover, PCA explains comprehensively a number of variable groups by avoiding multicollinearity due to too many predictors relative to the number of observations. PCA retains an appropriate number of factors, and reorients the data into a few components to capture as much information as possible from the original variables. This procedure also identifies patterns of association across variables and achieves maximum variance. PCA is run with multi-components. The first component of PCA is the linear combination of the original selected variables, while the second component describes an eigenvalue decomposition of a correlation matrix. In this study, PCA was run for the selected indicators of exposure, sensitivity and adaptive capacity using STATA 11 and the weights determined. The loadings from the first component of PCA are used as the weights for the indicators. The weights assigned for each indicator vary between -1 and +1, the sign of the indicators denoting the direction of relationship with other indicators used to construct the index.

Calculation of indices

The indices are calculated by normalising the values for indicators and subtracting the mean from the observed values divided by the standard deviation for each indicator. This point has been discussed in many academic papers such as Nelson et al. (2005) and Vincent (2004). In this regard, PCA provides assigned weights more properly, leading to unbiased reconstruction (Filmer and Pritchett 2001). The normalised variables are then multiplied with the assigned weights to construct the indices (for exposure, sensitivity and adaptive capacity) using the following formula:

$$I_j = \sum_{i=1}^{k} b_i \left[\frac{a_{ij} - x_i}{s_i}\right]$$

where, *I* denotes index value, *b* represents the loadings from the first component of PCA denoted as weights for identified indicators, *a* is the indicator value, *x* is the mean indicator value, and *s* denotes the standard deviation of the indicators. At the end, vulnerability index of the household is estimated as:

$$V = E + S - AC$$

where *V*, *E*, *S* and *AC* are the vulnerability, exposure, sensitivity and adaptive capacity indices, respectively. The whole vulnerability index simplifies interhousehold comparison within the targeted households. As a result, a high vulnerability index value indicates high vulnerability. However, this does not mean that a negative index value indicates that the household is not vulnerable at all. These index values provide a comparative ranking of the sample households. Test of analysis of variance (ANOVA) was carried out to compare the means among the three study locations, as well as the subgroup comparison.

Annex 5.2: Statistical results

Table A4: Mean values of subindices for adaptive capacity by location

Index	Kampong Chhnang			Kampong Thom			Pursat		
	Upstream	Downstream	P-value	Upstream	Downstream	P-value	Upstream	Downstream	P-value
Physical assets	0.18 (.95)	0.28 (1.02)	0.48	0.19 (1.04)	0.64 (.81)	0.00***	-0.49 (0.98)	-0.78 (1.36)	0.06*
Human assets	0.01 (1.22)	0.44 (1.19)	0.01**	-0.18 (0.96)	0.36 (1.06)	0.00***	-0.08 (0.87)	-0.24 (0.82)	0.18
Natural assets	-0.57 (0.87)	0 .35 (1.10)	0.00***	0.13 (1.03)	0.07 (1.16)	0.65	0.45 (1.09)	-0.15 (0.95)	0.00***
Financial assets	-0.11(0.67)	-0.05(.86)	0.58	-0.16 (.64)	0.36 (2.15)	0.00***	0.07 (0.80)	0.01 (1.03)	0.54
Social assets	0.27 (0.87)	0 .61 (0.76)	0.01**	0.11 (.84)	-0.46 (0.94)	0.00***	-0.18 (1.26)	-0.37 (1.16)	0.25
Adaptive capacity	-0.05 (0.53)	0.29 (0.62)	0.00***	-0.00 (0.47)	0.16 (0.70)	0.01**	-0.06 (0.55)	-0.31 (0.57)	0.00***

Note: Figures in parenthesis denote standard deviation; significant at *** 1%, ** 5% and * 10%
Source: Field survey, 2015

Table A5: Mean values of subindices for adaptive capacity by household gender

Index	Kampong Chhnang			Kampong Thom			Pursat		
	Male	Female	P-value	Male	Female	P-value	Male	Female	P-value
Physical assets	0.22 (1.09)	0.18 (0.88)	0.73	0.47 (0.91)	0 .29 (1.02)	0.13	-0.48 (0.95)	-.61 (1.17)	0.35
Human assets	0.02 (1.11)	0.13 (1.28)	0.49	0.23 (1.23)	-.09 (0.88)	0.01**	-0.01 (0.84)	-0.18 (0.87)	0.11
Natural assets	-0.51 (0.99)	-0.34 (0.98)	0.16	0.00 (1.01)	0.18 (1.12)	0.18	0.20 (1.06)	0.34 (1.11)	0.29
Financial assets	0 .01 ()0.80)	-0.15 (0.65)	0.04**	0.14 (1.63)	-0.02 (1.35)	0.33	0 .21 (0.85)	-0.02 (0.87)	0.02**
Social assets	0.39 (0.88)	0.31 (0.85)	0.43	-0.08 (1.06)	-0.12 (0.83)	0.70	0.04 (1.30)	-0.37 (1.19)	0.01**
Adaptive capacity	0.02 (0.59)	0.01 (0.55)	0.83	0.13 (0.61)	0.02 (0.56)	0.10	-0.01 (0.54)	-0.18 (0.57)	0.01**

Note: Figures in parenthesis denote standard deviation; significant at *** 1%, ** 5% and *10%
Source: Field survey, 2015

Table A6: All indices

Province	Exposure	Standard deviation	Sensitivity	Standard deviation	Adaptive capacity	Standard deviation	Vulnerability	Standard deviation
Kompong Chhnang	-0.57	0.67	-0.452	1.194	0.15	2.70	-1.18	3.23
Kompong Thom	1.41	0.54	-0.043	1.508	0.39	2.77	0.98	3.46
Pursat	-0.84	0.33	0.495	1.414	-0.55	2.71	0.20	3.10
P-value	0.00***		0.00***		0.00***		0.00***	

Note: significant at *** 1%, ** 5% and * 10%
Source: Field survey, 2015

Table A7: All indices by location

Province/ catchment	Location	Exposure	P-value	Sensitivity	P-value	Adaptive capacity	P-value	Vulnerability	P-value
Kompong Chhnang	Upstream	-0.40 (0.64)	0.00***	-0.49 (1.16)	0.24	-0.20 (2.50)	0.00***	-0.69 (3.08)	0.00***
	Downstream	-1.24 (0.00)		-0.29 (1.32)		1.55 (3.01)		-3.07 (3.12)	
Kompong Thom	Upstream	1.55 (0.63)	0.00***	0.420 (1.49)	0.00***	0.07 (2.22)	0.01**	1.90 (3.07)	0.00***
	Downstream	1.20 (0.21)		-0.76 (1.23)		0.90 (3.40)		-0.45 (3.56)	
Pursat	Upstream	-0.91(0.28)	0.00***	0.37 (1.41)	0.01**	-0.23 (1.61)	0.00***	-0.30 (2.97)	0.00***
	Downstream	-0.66 (0.33)		0.85 (1.39)		-1.48 (2.81)		1.67 (3.02)	

Note: Figures in parenthesis denote standard deviation; significant at *** 1%, ** 5% and * 10%
Source: Field survey, 2015

PART 3

Governance and Resilience

Chapter 6
Empirical and Theoretical Review of Climate Change and Water Governance to Enable Resilient Local Social-Ecological Systems

Louis Lebel, Sam Sreymom, Pech Sokhem, Ky Channimol

6.1 What is governance and resilience?

This review synthesises what is known about the ways in which water governance is likely to be important in increasing the resilience of sustainable local social-ecological systems to climate change and other stresses in developing countries. It draws on theoretical and empirical insights from around the world.

Water governance in this chapter refers to the ways in which power is exercised and distributed in negotiations, and how decisions are made on the development, allocation and use of water resources. Water governance is concerned with both the formal institutions of state and those institutions that arise from self-organised and collective action in communities. In many water governance systems there are multiple interests at play and actors with diverse capacities to access resources and influence decision-making at different levels. Taken together, these factors all indicate how studies of water governance can be intrinsically linked with the exercise of political authority. While this chapter predominately emphasises the management of rivers and the water resources used for agriculture, it will also consider how competition and conflict is relevant for other users.

Resilience has been defined as:

> … the potential of a system to remain in a particular configuration and to maintain its feedbacks and functions, and involves the ability of the system to reorganize following disturbance driven change. (Walker et al. 2002)

Resilience without qualification is a system property that is neither intrinsically good nor bad (Lebel 2006). A very "resilient" government might, for example, be authoritarian, corrupt and, ultimately, unsustainable. A highly human-modified grassland, for example, might be low in biodiversity, fire prone and of little economic value, yet resilient to disturbances, further ecological succession or various management interventions to change its state. It is therefore necessary to be more specific and clarify the resilience of what, to what, and for whom? (Lebel 2006; Carpenter et al. 2001).

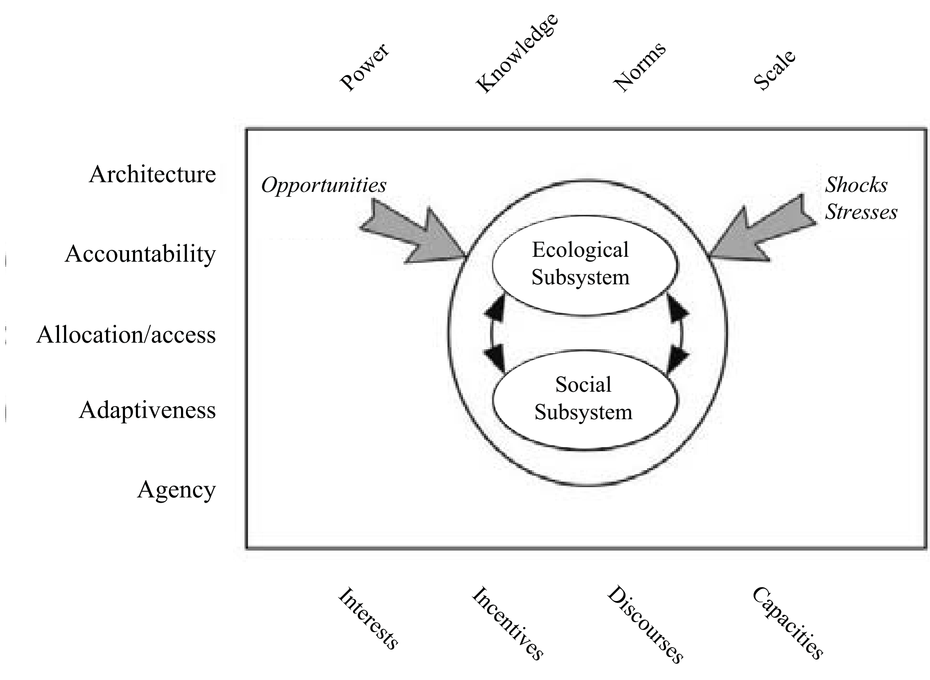
This chapter is interested in the resilience of sustainable local social-ecological systems—something inherently hard to define with perfect precision. A social-ecological system is one in which there are significant linkages, interactions, feedbacks or couplings between social and ecological subsystems (Ostrom 2009). An example of this would be a group of farmers dependent on a stream for irrigation and fish—they have particular interests (i.e. "for whom?") in the persistence of a system that supplies water for crops and fish to eat (i.e. "of what?").

Ecosystems services provided by a watershed, riparian vegetation, wetlands and instream flows and processes are often important to many different users (Brauman et al. 2007). "Local" here focuses on the uses, values and burdens (or risks) that are associated with particular places; like a village on the bank of a river. The emphasis on local is not meant to imply that other higher spatial scales are unimportant; indeed, drivers of change, shocks and disturbances often arise at other scales and therefore need to be taken into account when considering ways of improving water governance. Sustainable implies sufficient and equitable allocation or use without compromising the viability and integrity of the social-ecological system (Wiek and Larson 2012).

Which leaves the question of: "to what?" The primary interest here is in climate-related disturbances and stresses, such as extreme floods, disruption of natural seasonal flood pulses, seasonal shortages or multiyear droughts. We say "climate-related" because our expectation is that usually other factors, such as increasing demand on resources, will also be involved or be even more important than the climate variable itself.

In this chapter, we will focus on identifying insights that are relevant to developing countries. Developing countries are defined as political economies that include partial or incomplete democracies, highly centralised states, restrictions on freedom of speech and media, limited or modest financial resources, a moderate to low human development index score and influential multilateral agencies. While the focus of the study has been on developing countries, the performance, problems encountered and successes of more developed countries also form an important element of this chapter, as this reveals lessons learned from the implementation of various forms of governance.

Figure 6.1: Framework for organising insights on water governance for resilience of social-ecological systems



Source: Adapted from Biermann et al. 2010

The organisation of contents in this chapter are adapted from the framework developed by the Earth System Governance Project (Biermann et al. 2010) as outlined in Figure 6.1. The framework identified five main themes or lenses: institutional architecture, accountability, allocation and access, adaptiveness and agency. It also highlighted four crosscutting issues: power, knowledge, norms and scale. To these, four more were added that are important in analysing the political economy of water and its impacts on local social-ecological systems: interests, incentives, discourses and capacities. The underlying message is do not overlook the importance of politics in the pursuit of climate change adaptation, sustainability and resilience.

6.2 Architecture

6.2.1 Interplay and coordination

It is important to consider the arrangements or architecture of governance regimes when investigating interaction or interplay among institutions (Young 2002a). Horizontal interplay is usually concerned with the problem of integration (sectors) or coordination (places). Vertical interplay on the other hand, is usually more about the distribution of power and coordination (levels).

The integration of climate change adaptation into water resources development and management requires a shift in perspective from governments who have conventionally seen climate change as a discrete issue, rather than an additional consideration when managing development risks. Much greater integration among sectors is needed. In the water sector, the solution that is usually promoted is the ideal of integrated water resources management (IWRM), though this is not without major challenges.

A comparative study of governance approaches in 18 river basins in Brazil found a positive relationship between indicators of integration in water governance with measures of adaptive capacity (Engle and Lemos 2010). In-depth analysis in four of those basins, however, suggests some trade-off in specific dimensions; for example, between equality of decision-making and knowledge availability. It has been suggested that IWRM in the Ebro River catchment of Spain has been a failure; plans for further expansion of irrigation are proposed although water availability is declining and expected to shrink further (Bielsa and Cazcarro 2015). They underline institutional coordination as a key problem. While there was a formal participation process in the initial preparation of the basin hydrological plan, more powerful and centrally connected interests in the Water Council increasingly tended to dominate discussions.

In a comparison of the governance of 29 national river basins in developed and developing countries, Pahl-Wostl et al. (2012) found that institutional architectures which distribute power horizontally and vertically, but still maintain effective coordination, perform better on most measured criteria. In this analysis, the performance criteria included sets of indicators related to: (1) meeting the Millennium Development Goals, (2) realisation of good governance principles and stakeholder involvement, and (3) existence of climate adaptation policies. Such polycentric arrangements allow responses at various spatial scales, and ability to cope with diverse capacities and impacts in various sub-basins.

Scale issues are an important dimension of many water governance challenges and capacities, and multilevel forms of governance are important to the response capacity of societies (Adger and Vincent 2005) and governance actions at different levels. These range from actions at the local level through to actions at the river basin level and, ultimately, even internationally (Lebel, Garden and Manuta 2005; Sneddon 2002). Typically they look to have resources allocated to the levels where they are strongest or have the biggest interests, and push unpleasant duties and responsibilities elsewhere. As a consequence, effectively engaging actors in bureaucratic and political hierarchies requires an understanding of how interests, influence and capacities vary with scale.

In transboundary river basins, even when the primary interest is in the resilience of local livelihoods, it can be important to consider how international relations influence and obstruct adaptation. Kranz, Meniken and Hinkel (2010) used an analytical framework based on regime effectiveness theory to show that the Mekong Basin has made more progress towards adaptation policies than the Orange-Senqu River Basin in Africa. They attribute relative success in the Mekong region to several factors, including regional procedures and structures which support flexible collaboration. At the same time, they note tensions with less developed national strategies, which could be barriers to transboundary strategies, an example of vertical interplay.

At more local scales, where self-organisation is plausible, there is a large body of literature on institutional design and water management performance, some of which is now engaging with governance issues under climate change. Local water storage, for example, is critical for dealing with seasonal shortages in the Hindu Kush Himalayas (Vaidya 2015). A diverse set of practices in rainwater harvesting, groundwater storage and wetland conservation in the Hindu Kush met many of the best practice design rules proposed earlier by Ostrom (1990) and tended to work effectively. Vaidya (2015) suggests that larger government-led watershed initiatives should learn from these local experiences; in particular, by ensuring active participation of local water users, and making sure that new arrangements do not disrupt existing informal cooperative structures and norms of reciprocity.

The social institutions that underpin water sharing in gravity-based irrigation systems have historically been the foundations for developing cooperative responses to climate variability (Shivakoti et al. 2005). However, in Northeast Thailand, diversification of land uses and income sources along with commercialisation appear to have reduced the strength of some of the cooperative ties in former rice-growing communities (Chinvanno et al. 2008). Closer relationships to markets have also constrained adaptation options, as consumer preferences for particular varieties dominate cropping decisions at the expense of more tolerant and varied local rice varieties.

When state capacity is adequate, various forms of co-management and greater formal coordination are plausible. However, when state capacity is low, informal local institutions and self-management become essential. Therefore, to improve water governance in highly centralised states, there is usually a need for decentralisation. For water resources, as uses grow and users multiply, upstream-downstream and left-right bank types of relationships become more complex; and coordination beyond individual locations is often needed. Polycentric institutional architectures appear to enhance water governance in these situations.

6.2.2 Fit

Many scholars have argued the importance of achieving an adequate fit between institutional architecture and the social and ecological system they are embedded in (Young 2002b; Folke et al. 2007; Ostrom 2010). In some instances, knowledge of ecological processes may be built directly into institutional designs (Berkes, Colding and Folke 2003, 1998). A good fit is expected to improve the capacity to manage resilience. In the case of managing the impacts of large-scale water infrastructure on ecosystems, this might include negotiations and agreements on environmental flows (Pahl-Wostl et al. 2013).

Water sector reforms that included a shift from administrative to hydrological boundaries in South Africa involved two key trade-offs: between improving the fit between the social and the ecological system and worsening the fit between levels within the social system; and between correctness of classifications along hydrological boundaries and the feasible size for effective management, meaningful stakeholder participation and financial viability (Herrfahrdt-Pähle and Pahl-Worstl 2010). Negotiating these trade-offs requires intense communication, cooperation and coordinated action between the involved organisations (Herrfahrdt-Pähle 2010). Improving the spatial fit with hydrological boundaries, for instance, increased the need for coordination with other water management organisations. These observations led the author to propose also considering the fit with existing water service infrastructure, climate change, and political and economic dimensions.

Similarly, Lebel et al. (2013) proposed six measures of fit—allocation, integration, conservation, basinisation, participation and adaptation—and used these to demonstrate the important role of context in institutional performance across 28 national river basins from around the world. As different fit measures within a basin often diverge, the authors conclude that it is challenging to simultaneously achieve a high fit against multiple challenges.

Upland watersheds provide a range of water-related ecosystem goods and services (Braumann et al. 2007) at multiple scales (Lebel et al. 2008). Obtaining sufficient information about these services is a common challenge for planning (Turner and Daily 2008); planners may have to draw on local knowledge that is only available if authorities allow meaningful local participation in land-use planning and water allocation (Thomas 2006; Daniel and Ratanawilailak 2011). Watershed management committees or networks established to inform planning usually have little formal authority, but can still help with conflict resolution and negotiation. Payments for environmental or ecosystem services are an incentive-based complement to spatial planning and regulatory approaches to conservation of watersheds and their services (Wunder 2008; Engel, Pagiola and Wunder 2008). Quito, the capital city of Ecuador, for example, has a Water Fund that draws on contributions from water users and donors to fund projects that improve the watershed which provides its drinking water (Tallis et al. 2009).

In summary, while it is important to consider the social-ecological system in institutional design, in practice it is challenging to achieve a good fit with multiple dimensions or criteria simultaneously. Nevertheless, a shift towards more polycentric institutions will usually help, as such architectures allow greater flexibility in pursuing problems of inadequate fit, as well as greater specificity in monitoring and learning than is possible in more centralised systems.

6.3 Accountability

6.3.1 Upward and downward

The legitimacy of an authority to govern adaptation at the local level is enhanced if it is perceived as accountable and transparent (Termeer et al. 2011; Tennekes et al. 2014). Accountability means accepting responsibility for one's actions, which may be with respect to standards of behaviour or the sanctioning power of those governed (Biermann and Gupta 2011).

Decentralisation reconfigures responsibilities and power relations in institutional architectures; one common way for higher (more central) levels to maintain authority is to insist on mechanisms to hold local authorities upwardly accountable. This usually implies meeting new monitoring and reporting requirements (Agarwal et al. 2012). In the other direction, it is important that local and national authorities are downwardly accountable to local communities, otherwise the small and large projects they undertake in the name of adaptation may not yield promised benefits or may have adverse side-effects on local social-ecological systems (Lebel et al. 2009).

Attention to accountability mechanisms is especially important when rights to water are being negotiated and redistributed (Ratner et al. 2013). In the Netherlands, for example, a greater emphasis on individual responsibility for adaptation to climate change impacts on groundwater underlines the lack of appropriate accountability procedures regarding municipal responsibilities (Bergsma, Gupta and Jong 2012). Similarly, studies of responsibilities for managing flood risks in Rotterdam, Hamburg and Helsinki noted that networks, participation and deliberation did not automatically lead to more accountable or legitimate arrangements as is frequently expected (Mees, Driessen and Runhaar 2014). Private individual actors, it turns out, are hard to hold accountable for how they manage flood risks.

In large-scale hydropower development, a key governance issue is improving the accountability of project developers and authorities to affected people. In the case of Laos, analysis of the Nam Theun 2 hydropower project suggests this should include giving more voice in early planning decisions about whether projects should go ahead or not; and when they do, to make sure that there is proper compensation, ongoing sharing of revenues and other benefits for those adversely affected (Lawrence 2009). Accountability is also important with respect to financial flows for water infrastructure projects. In Indonesia, corruption within the irrigation bureaucracy results in maintenance being deferred, and the perpetuation of a cycle of donor support that benefits political elites (Suhardiman and Mollinga 2012).

Market-based instruments such as certifications are potentially another approach to improving accountability. In Central Kalimantan, Indonesia, certification under the Roundtable for Sustainable Palm Oil has not led to significant improvements in water resources management, nor have concerns with impacts on local livelihoods been addressed (Larsen et al. 2014); a combination of state regulations and certification may therefore be necessary. Adherence by developers to voluntary standards, such as the hydropower sustainability assessment protocol (Foran 2010), may provide another avenue for improving accountability.

In Cambodia, a network of villages engaged in collaborative research improved the responsiveness of commune councils to residents' needs. While in Bangladesh, supporting a fisheries society resulted in local government and the fisheries department becoming more responsive to the needs of poor households. These two examples illustrate the importance of informal mechanisms for strengthening accountability (Ratner et al. 2013).

In many developing countries, accountability mechanisms for water-related projects and policies are underdeveloped. Improving water governance therefore implies seeking to strengthen existing and establishing new ways to question and sanction authorities and developers. A combination of formal safeguards, such as independent social and environmental impact assessment procedures, regulations, voluntary standards and other less formal approaches should be encouraged.

6.3.2 Transparency and monitoring

Monitoring and evaluation in adaptation is important because of the large uncertainties associated with both climate change and the impacts of newly formulated policies and projects (Clarvis et al. 2014). Uncertainties about the impact of climate change make information exchange very important; but many national governments still see the sharing of water data as a national security issue and therefore tightly restrict access to data (Lebel, Grothmann and Siebebhuner 2010).

Agarwal et al. (2012) suggest that decentralised adaptation policies can be made more effective if local capacities are strengthened. They also emphasise the sharing of information and the monitoring of newly empowered local authorities' accountability to their constituents. Transparency of local decision-making processes can reduce the risks of local elites capturing local governments (Bardhan 2002).

In the case of large dams, a key issue for affected communities is to have access to project information. Civil society actors may also become involved in pressing for disclosure of project information; in particular, with respect to who is financing and likely to benefit, and who will pay or be made more vulnerable (Huber and Joshi 2015; Merme et al. 2014). In Nepal, opponents at both ends of the proposed Melamchi tunnel project to supply water to Kathmandu formed a coalition of local and national organisations to make formal demands for improved access to information, including greater transparency in land acquisition, resettlement and compensation procedures (Domènech. March and Sauri 2013). In these types of situations, civil society actors often play a critical watchdog role and help bridge between coalitions. In the case of hydropower dams already certain to be constructed, issues of monitoring and transparency shift to the distribution of benefits and compensation for burdens or risks (Lebel Chitmanat and Sriyasak 2014; Men et al. 2014).

New rights to information laws in Nepal, India and Bangladesh have made little difference in practice to public access to data on transboundary rivers, such as the Ganges, as administrative procedures are not well developed (Prasai and Surie 2015). The laws provide a legal framework for improving transparency in water governance, and advances in information and communication technologies make disclosures to a broader audience simpler. But, as the authors point out, a lot still depends on political will.

In summary, improving the accountability of authorities at all scales is important to improving the quality of water governance, especially for the users of local social-ecological systems. Being able to access information about projects, and sanction those whose behaviour does not meet accepted standards, are important to those who otherwise hold little power. Informal and formal mechanisms are both relevant.

6.4 Allocation and access

6.4.1 Procedural justice

Throughput legitimacy, or procedural justice, relates to the idea of fairness in the rules and procedures used to reach decisions. These aspects of procedural quality can arise through citizen participation in deliberation and judgements (Paavola 2008; Dryzek 2000). A typical scenario is conflict over water allocation, easily exacerbated by altered water flows related to climate change (Gupta and Lebel 2010). Multi-stakeholder dialogues, by creating and supporting meaningful conversations, can help reduce water conflicts and allow fairer allocation. Dialogues may also inform and help shape more formal negotiation and decision-making processes, by bringing in a wider range of perspectives on needs, impacts and options, and having them deliberated upon openly (Dore 2007; Dryzek 2000). During the last decade, dialogues around water resource infrastructure projects and management policies have proliferated around the world, at many different levels of governance. The dialogues vary widely in how strongly they are driven by water management agencies within states, and consequently, how tightly they are linked to decision-making and investment processes.

In a comparison of local flood risk strategies in Hamburg, Helsinki and Rotterdam, Mees, Driessen and Runhaar (2014) found that Rotterdam had a higher quality of participation and deliberation among public and private stakeholders. In this case, residents hired a consultant skilled in deliberation to help represent their interests. The high throughput legitimacy did not, however, result in comparatively higher output legitimacy as might have been expected. This may have been because of the overall high level of stakeholder acceptance found in all three cases regarding adaptation solutions and divisions of responsibilities.

Efforts to marketise and centralise control over water in Peru are similarly contested (Lynch 2012). Analysis of competition trends under a variable climate in the Rio Santa watershed suggests that high elevation rural communities and the urban poor are likely to lose access to water. Although equity concerns and rights are addressed in Peru's 2009 Water Law, concerns remain that ambiguities will be exploited by strong economic interests from mining, hydropower and agro-exports. In response, Lynch (2012) argues for improved representation of vulnerable groups in watershed bodies and negotiations; that, in turn, requires a strategy of coalition building, forming both upstream-downstream links, and links with other sectors and places (Lynch 2012). In Arequipa, the creation of a new river basin council under the new law was built on the experience of an earlier informal, multi-stakeholder process for water management in the area (Filippi et al. 2014).

Concern remains that it will be difficult to represent all members' interests fairly because a large mining company that finances water infrastructure has a lot of power and influence over the region.

One of the main limitations of the resettlement programme for the Son La Dam project in Vietnam was achieving the meaningful participation of displaced residents in key decisions (Van Ha 2012). Cultural and language differences were significant barriers leading to heterogeneity in procedures and outcomes, as were local people's lack of capacity and empowerment and local authorities' lack of necessary skills to enhance public engagement.

In summary, when exploring and formulating adaptation policies in the water sector, it is imperative that vulnerable people are properly consulted. The objective should be empowerment which expands the options, opportunities and quality of local adaptation. Poor farmers need social, economic and political "space" in which to exercise their expertise and rights in order to adapt. Unfortunately, many water agencies are not aware of the benefits of participation, deliberation and negotiation with stakeholders in making plans and taking action. In these situations, improving the fairness of water governance requires strengthening the representative capacity of marginalised interests.

6.4.2 Outcome justice

One approach to improving fairness and justice in water management is through securing the rights to water of vulnerable or marginalised social groups (Gupta and Lebel 2010). In many countries, the rights to access and use water are not clear; in others, even when they are legally explicit, rights may not be respected in practice. Either way, rights may be contested, and thus progress in defining and securing rights often requires negotiation (Bruns and Meinzzen-Dick 2000).

The wider political economy drives changes in the resilience of local livelihoods. In the Mekong region, "unjust governance practices" make poor and marginalised social groups even more vulnerable (Nuorteva, Keskinen and Varis 2010). The rights of fishers to secure livelihoods and of small-scale farmers to access water are undermined by unsustainable patterns of development that tend to reinforce social differences (Resurreccion et al. 2012).

An evaluation of six World Wide Fund for Nature (WWF) climate change adaptation projects concerned with river management concluded that efforts to reduce physical vulnerability should be paralleled by measures to improve livelihoods (Pittock 2009). The projects identified many small-scale "no-regret" and "low-regret" measures that would be good for both livelihoods and nature conservation. The author suggests that it makes sense to start with such measures—to build capacities and a sense of success—before tackling more challenging and often large-scale problems. In Morogo, Tanzania, Paavola (2008) argued that effective governance of natural resources such as forest and water was highly complementary to farming-related adaptations, which functioned as safety nets for particularly vulnerable groups.

New markets for ecosystem services in upland watersheds need to be introduced carefully because they might disrupt existing rights of access (Mollinga, Meinzen-Dick and Merrey. 2007; Corbera, Brown and Adjer 2007). Poor and vulnerable groups are often more dependent on ecosystem services, but lack the capacities to engage in formal schemes (Jack, Kousky and Sims 2008). Smallholder farmers in Vietnam, for example, were unlikely to join reforestation schemes unless compensation was adequate to cover loss of food production (Jourdain et al. 2009). Those excluded or choosing not to participate in such schemes may also be placed at a disadvantage, such as when the landless lose access to common pool resources as a consequence of scheme regulations (Wunder 2008). The incentive for providing ecosystem services does not have to be cash to an individual; payments might be made to a group, and be about other benefits like land tenure or capacity building (Need and Thomas 2009; Leimona, Joshi and Noordwijk 2009).

Charging for water in smallholder irrigation schemes has often been suggested as a way to drive improvements in water efficiency or reduce overall water demand—a potential adaptation strategy in water allocation for areas facing reduced rainfall (Sowers, Vengosh and Weinthal 2011). In practice, implementing such policy is fraught with technical, economic and political challenges that could further marginalise smallholder farmers (Molle and Berkhoff 2007).

In irrigation, women often have less access to water than men, reflecting differences in property rights and management roles (Meinzen-Dick et al. 1997; Zwarteveen 2008). Women may have to access water through husbands or male relatives (van Koppen and Hussain 2007). In water and river management organisations, women are often underrepresented; this probably contributes to their vulnerability (Huising and Kevany 2013). Blindly promoting women's greater participation in water governance may multiply burdens rather than empower (Ivens 2008; Resurreccion and Manorom 2007). Impacts of and responses to climate change may differ between men and women as a consequence of differences in access to resources, livelihoods and decision-making power (Figueiredo and Perkins 2013).

Gaining public acceptance was identified as a strategic priority in the World Commission on Dams report on decision-making (WCD 2000). Most of the emphasis was on gaining legitimacy through good procedures; for example, inclusiveness and access to information. Outcome or distributional justice is also important, and includes not just sharing of benefits, but also the allocation of involuntary risks (Dore and Lebel 2010).

In summary, just procedures and outcomes are both important to the legitimacy of water authorities and their projects; without them, public acceptance is low. Issues of fairness and justice arise with respect to the distribution of burdens, opportunities, risks and benefits from specific projects and broader policies.

6.5 Adaptiveness

6.5.1 Flexibility

As the uncertainties involved are large, planning processes that attempt to bring climate change considerations into water or disaster management should treat policies, projects and strategies as experiments. Mechanisms to make observations, get feedback from diverse stakeholders and adjust implementation as it is ongoing—literally, learning by doing—should be incorporated from the start (Pahl-Wostl et al. 2008). At the same time, climate change adaptation policies need to be stable enough that they can be pursued, but flexible enough that they can be modified (Jordan and Huitema 2014). In particular, recent examples of policy innovation suggest that policies that are flexible with respect to how policy goals are met usually tend to be more effective.

Tensions between continuity and change were also apparent in a comparison of water governance case studies from Uzbekistan and South Africa (Herrfahrdt-Pähl and Pahl Wostl 2012). In South Africa, reform was much more comprehensive, including changes to constitutional rules, but the process took a lot of time and resources. Flexibility in the legislative processes meant that legislation could be dealt with in parts and in phases. In Uzbekistan, on the other hand, a rigid institutional structure that grew out of a historical high dependence on irrigated cotton monoculture has prevented more transformative or coherent institutional responses to severe environmental degradation.

Huntjens et al. (2012) found evidence of adaptation strategy development in the Netherlands and Australia; leaving some responsibilities and relationships open allowed for process robustness and flexibility, even if doing so meant some overlap of mandates. A flexible process meant roles could change; for example, to include bottom-up initiatives to represent local stakeholders in regional and national committees. The authors also argued that a flexible process helped build realistic expectations and trust among participants.

In the Upper Rhone Basin in Switzerland, rules on water pricing, provision and use are set at commune or canton level, and allow some flexibility for dealing with new challenges like climate change (Clarvis et al. 2014). While flexibility at the local level is important for reactive measures, high local autonomy can be a barrier to long-term, large-scale adaptation policies (Hill 2013).

Using a hydro-agro-economic model of the Indus River within Pakistan, Yang et al. (2014) find that the current rigid water allocation system has not only prevented provinces from being able to adapt to changing climate conditions, but would also inflict significant economic costs under both high and low flow scenarios. In response, the authors call for more adaptive approaches. Similarly, in the Ganga Basin in Nepal and India, Moench (2010) argues for the importance of regular critical review of strategies, and to adaptively shift strategies based on this knowledge.

Barrages on the Ganges already divert as much as 60 percent of flows to large-scale irrigation schemes. The Farakka Barrage (built in India in 1975 and just 18 km from the Bangladesh border) greatly reduces average monthly discharges. As glacial melting due to climate change takes effect, water flows in the Ganges could drop by two thirds in the long term (B. Sharma and D. Sharma 2008). The 1996 Ganges Water Treaty includes provisions for releases to Bangladesh, which is vulnerable to changes in the allocation policy (Rahaman 2009). For example, the current sharing arrangement is based on a 40-year historical flow record. The details of water-sharing agreements may need to be adjusted as flows change. Comparative analysis shows that treaties on transboundary rivers that are flexible and specific result in more cooperative behaviour between states, especially when water availability varies (Dinar et al. 2015).

Many studies have concluded that capacities for adaptive governance in the water sector are underdeveloped. In the Middle East and North Africa, for example, governments have focused almost entirely on augmenting supply, and have not paid enough attention to managing water demands (Sowers, Vengosh and Weinthal 2011). Their technical and infrastructure driven approach has meant that procedures to engage stakeholders are underdeveloped. Consequently, important social and political challenges with respect to water allocation and access have not been addressed.

IWRM in Brazil is founded upon a history of technical and hierarchical management that, while more accountable than the centralised command-and-control logic of the past, may lack the flexibility to innovate and support adaptive management (Engle 2011).

Existing legal frameworks in three US regions have been criticised by stakeholders for posing a barrier to integrating knowledge about climate variability, let alone climate change, into water allocation and management decisions (Dilling et al. 2015). In the Great Lake states, for example, there were concerns over modifying agreements negotiated with provinces in Canada to manage water supply and protect ecosystems. In another region in western US (Colorado, Wyoming and Utah), a complex system of water rights with a long history was seen as daunting to change.

In summary, a degree of flexibility in regulations and roles is important for dealing with changing and uncertain water resource conditions. Simultaneously, however, many water bureaucracies and institutions appear to be particularly rigid and not well suited to adaptive approaches to governance. Flexibility, for example, could be fostered by allowing water rights to vary in anticipation of changing conditions, or by imposing emergency provisions within the water rights system during drought and flood events. An important constraint for developing countries is that the implementation of adaptation policies, programs and measures requires adequate financial and technical capacity, as well as sufficient and accessible hydroclimatic data.

6.5.2 Learning

Adaptive governance emphasises learning and knowledge, and managing resilience or building adaptive capacity (Folke et al. 2005; Pahl-Wostl 2009). Learning may be through formal monitoring and assessment, systematic processes for learning from past interventions, anticipation of changes and deliberation among diverse stakeholders (Pahl-Wostl et al. 2008; Armitage et al. 2009; Swanson and Bhadwal 2009).

Huntjens et al. (2012) extended Ostrom's (1990) work on institutional design principles. This expanded the learning needed to deal with the complexity and uncertainties related to climate change impacts in the water sector. Empirical cases of adaptation strategies in place in the Netherlands, Australia and South Africa illustrated the importance of social learning and policy learning for adaptation. Processes that enable learning and build trust are important because they support the exploration of uncertainties and deliberation of alternatives, which, in turn, can lead to critical reframing of problems and solutions.

A study of a participatory initiative with multiple stakeholders to identify adaptation options for the Niagara Region, Canada, distinguished three types of learning: cognitive, relational and normative (Baird et al. 2014). Evidence, including comparisons with a non-intervention group, suggested participation resulted in cognitive and relational learning; but no evidence for normative learning, or shifts in viewpoints or values could be detected in this case.

Social learning inspired processes have been widely used to try and help stakeholders understand each other's perspectives and interests. Small group approaches have, for example, been successfully used with key administrators in the degraded Lake Baiyangdian catchment in China (Wei et al. 2012).

Action or collaborative research is one approach to fostering social learning for adaptation. In a study with a water utility in the UK, researchers found that a reflexive process of opening issues for debate, followed by an effort to bring discussion to a closure by identifying next actions, was challenging because practitioners and researchers had different understandings of current knowledge (Westling et al. 2014). Making things "less comfortable" (for practitioners or researchers) can put a collaboration at risk, so trust is important; and sometimes compromises may be needed with respect to what is "usable" knowledge.

Learning and collaboration are the main pillars of adaptive co-management (Armitage et al. 2009). In dealing with complex problems, where cause-and-effect relationships and future dynamics are uncertain, trust needs to be developed among stakeholders so that when new circumstances demand changed practices, stakeholders are willing to deliberate and negotiate the next steps (Berkes 2009).

Initially successful social learning approaches to IWRM in local catchments in England and South Africa were subsequently marginalised as a result of lack of support by national government (Colvin et al. 2014). A recurrent issue was that key senior officials that had engaged earlier in the process changed jobs; thus experience and relationships were lost.

Political cultures also matter. In the Delta programme for the Ijsselmeer Region in the Netherlands, detailed discussions around adaptation options resulted in learning, but were met with apathy by elected politicians. In contrast, in the flood committees of East Anglia in the UK, rules and responsibilities were more clearly defined. This resulted not just in learning, but also in deliberations that led to negotiations and action (Vink et al. 2015).

Social learning can improve the capacity of a social-ecological system to adapt to environmental changes (Lebel, Grothman and Siebenhuner 2010). In particular, it can help actors cope with informational uncertainties and move them towards more adaptive forms of governance. Social learning can also reduce normative uncertainties; for instance, with respect to differences in goals or what constitutes acceptable risk. Case studies of water management in the Alps of Europe and in the Mekong region suggest that while social learning in multi-stakeholder dialogue processes can reduce conflicts, it may still leave issues of coordination unresolved, especially at larger regional scales (Lebel, Grothman and Siebenhuner 2010).

Developing countries often face the dual challenge of modest scientific capacities coupled with limited capacity of authorities to use available scientific resources. Improving water governance may thus also be about building co-productive capacity or:

> … the combination of scientific resources and governance capability that shapes the extent to which a society, at various levels, can operationalize relationships between scientific and public, private, and civil society institutions and actors to effect scientifically-informed social change. (van Kerkhoff and Lebel 2015)

In summary, flexibility and learning are expected to be important predictors of effective water governance systems under a changing climate. In contrast, empirical studies have often found water bureaucracies and rule systems to be rigid, implying that adaptive governance capacities remain low. A high technological dependence on large infrastructure to augment supply may impose rigidity and path-dependency constraints on governance systems. What constitutes an appropriate balance between stability and flexibility in policies and local institutions remains an open research question.

6.6 Agency

6.6.1 Depoliticisation and resistance

More inclusive participation and open deliberation is important in complex situations, as this helps build trust and shared understanding among stakeholders. As indicated by Lebel (2006), this also becomes crucial to mobilise resources and people. While highly structured policy problems are amenable to technocratic responses and usually demand minimal public participation, problems involving disagreement over values or knowledge typically demand more public participation (Hurlbert and Gupta 2015). Resistance and non-engagement is also a relevant tactic in some situations where participants do not want to be perceived as legitimising a process they see as seriously flawed (Dryzek 2001).

In the Melamchi project in Nepal, rural residents struggled for political recognition; they also pushed for a greater share of the financial benefits from the interbasin transfer of water (Domènech, March and Sauri. 2013). In this particular case, these gains only came after a combination of serious complaints to the financier and acts of sabotage to halt initial project work. In contrast, non-state actors in Switzerland have rights to challenge water resource development decisions in court, and this has enabled environmental groups to influence legislation and policy (Clarvis and Engle 2015).

A common tactic of large-scale water infrastructure developers is to try and depoliticise projects. One way this is achieved for hydropower is to appeal to green growth and climate mitigation or other win-win narratives (Käkönen et al. 2014; Huber and Joshi 2015). Doing so shifts attention away from local impacts, which can include displacement, disruption of fishers' livelihoods and ecological effects. Depoliticisation may be pursued by making issues technical, and thus out of reach of ordinary citizens (Käkönen et al. 2014); but also by coercion, intimidation and other undemocratic machinations (Huber and Joshi 2015). In response, local communities and civil society groups counter powerful actors with arguments and initiatives that re-assert their rights and roles in decision-making.

Gerlak and Schmeier (2014) analysed the climate change discourses of the Mekong River Commission (MRC) in their official documents. Most strategies are framed as science-based actions, though links are also made to security, justice, IWRM and development. The authors suggest the multiplicity of justifications was a way for the MRC and its members to secure donor support. To date, climate change actions have been mostly in the form of studies with little cost to member states, as they have been donor-funded and no-regret options.

Glacier recession has changed water availability in the Santa River catchment in Peru, with dry season discharge now falling (Wrathall et al. 2014). Growing water demands of coastal plantations, cities and hydropower have resulted in new tensions and conflicts (Carey, French and O'Brien 2012). Upland households have responded to shortages and water use restrictions with limited diversification strategies that include migration elsewhere for employment; this is especially the case in subcatchments which are now dependent almost entirely on rain rather than glacier melt (Wrathall et al. 2014). The limited options for local smallholders reflect their inability to negotiate fair access to water with other much more powerful actors in mining and hydropower; hence migration is seen as the only way out of the situation. In 2008 a coalition of local communities living below glaciers in Peru seized control of Lake Parón reservoir from a private multinational energy corporation (Carey, French and O'Brien 2012). Their actions were in response to negative impacts on local irrigation. Tunnels and gates installed two decades earlier to prevent lake outburst floods triggered changes in water management that later led to increased use and competition for water and, ultimately, this conflict.

It has been indicated how non-state actors clearly have agency in water governance and adaptation, often despite the best efforts of states and corporations to depoliticise issues. Depending on political contexts and power relations, local communities, civil society organisations, or large multinational corporations and banks, may be influential around specific water negotiations and decisions. Resistance and struggle may be a necessary part of transforming governance into one which supports more resilient local development and water resources management.

6.6.2 Networks and coalitions

One reason network ties are so important for adaptive governance is the diversity of knowledge they can bring to bear on a problem. Preserving and documenting diverse sources of knowledge creates a larger foundation of ideas which actors can draw upon. Networks are critical to learning processes and the emergence of adaptive governance (Pahl-Wostl 2009); and informal or shadow networks are often crucial for preparing a governance system for change (Olsson et al. 2006). Such networks that are not burdened by conventional hierarchies and bureaucratic norms allow leaders and others with power or influence to pursue shared understanding and explore alternatives. People in such networks may not be restricted to representing organisational interests and bargaining, as is the case for people who are restricted by conventional networks that are bound to hierarchies (Pahl-Wostl 2009). Key individuals in informal networks may take on roles of knowledge brokers or boundary spanners (Olsson et al. 2006).

Clarvis and Engle (2015) compared the bridges and barriers to adaptation in the water sectors of Canton Valais, Switzerland, and the state of Georgia, USA. They identified trust within actor networks as common bridges, as these were important to the communication of hydrological information during times of crisis. In Georgia, formal associations of water professionals and water agencies supported regional collaboration and coordination. In Switzerland, cross-level partnerships among government agencies and universities or research institutions resulted in valuable information networks that informed evaluation of adaptation options.

In the Murray-Darling Basin in Australia, institutional responses to climate change are making water governance more complex (Wallis and Ison 2011).

To deal with the potentially growing administrative burden and stakeholder confusion, regional water managers draw on the social capital they have accumulated in their relationships with other managers. The authors argue it is important to acknowledge and maintain this social capital as reforms are pursued.

In countries with ineffective formal institutions, it may be necessary to turn to, and depend more on, informal civil society and local processes and actor networks to improve water governance (Pahl-Wostl 2012, 2009). In the Nam Songkhram Basin wetlands in Northeast Thailand, struggles over local natural resource management issues helped drive new forms of participation (Blake, Friend and Promphakping 2009). The villagers themselves led knowledge gathering and documentation, and by developing solidarity they engaged more effectively with external actors and regional development processes.

There is now substantial experience around the world in partnerships and coalitions for managing small and intermediate-sized watersheds (MacPherson and Tonning 2002; Wittayapak and Dearden 1999). In Thailand, for example, the Department of Water Resources has been pursuing integrated water resources management through a consultative, multilevel planning process coordinated by river basin and sub-basin organisations (Thomas 2005). Many other processes have been established by water users themselves (Molle 2005).

A detailed study of river management policy debate on flood management in the Tisza River in Hungary from 1997 to 2009 identified governance and information management as “bridges” that enabled new ideas to enter into policy processes (Sendzimir et al. 2010). The agency of non-state actors was also shown to be critical (Werners et al. 2009). However, without sustained leadership, transformation stalled with other excluded sector actors becoming key barriers to change (Sendzimir et al. 2010).

In brief then, coalitions are important both for progressive change and for maintaining the status quo. States themselves are not monolithic: different agencies, for example, may visibly or more quietly align with different coalitions in favour of, or in opposition to, large-scale water infrastructure projects. Social networks are important for cutting across formal administrative hierarchies and dealing with ineffective institutions.

6.7 Discussion and conclusions

Conventional water governance can be characterised as centralised, expert-driven, compartmentalised and change-averse. Conventional governance assumes and forecasts influence, order and stability. Authority is unchallenged and assumed to be legitimate. In conventional systems, ecosystems are seen as separate from society and economics; and failure to achieve management objectives is attributed to a lack of financial or human resources.

In contrast, adaptive water governance focuses on learning and managing resilience. Adaptive governance accepts uncertainty, partial control and complexity of outcomes. Authority is challengeable and multicentred. When forward-looking, adaptive governance is concerned with being prepared for the unexpected. When reflexive, it is concerned with learning from experience. Social and ecological systems are seen as intricately interconnected and dynamic.

Adaptive governance needs to be inclusive, as social, ecological and technological shifts to pursue sustainability require negotiation and evaluation of interventions in the context of uncertainties about causes, impacts and multiple interests (Lebel 2006; Smith, Stirling and Berkhout 2005). Inclusiveness is important for deliberations to be well informed, for fair representation of interests and for shared learning. At the same time, it should be underlined that knowledge production in these situations is never independent of politics; it is therefore important to acknowledge how assumptions of models, scenarios, assessment scopes and choice of scales frame what is considered and what is not (Käkönen and Hirsch 2009; Lebel 2006).

Water bureaucracies have a long history built on highly technical, top-down approaches to management that emphasise large-scale technologies (Molle, Foran and Kakonen 2009; Pahl-Wostl 2009). This has made the introduction of more adaptive and inclusive procedures a slow and difficult process in most countries. Agencies are simply not skilled in or aware of the benefits of meaningful participation of stakeholders in their planning and decision-making procedures (Gyawali and Dixit 2001; Pahl-Wostl 2007). Commitments to IWRM have opened some opportunities for wider engagement. An example is when consultation processes are mandated as part of the normal business of basin organisation. In practice, however, much decision-making remains outside that process (Molle 2008).

Integration is a recurrent and fundamental challenge for pursuits of sustainability where bureaucracies are fragmented along ministerial lines. Institutional mechanisms to assist coordination and cooperation in strategic policy and planning are needed to avoid conflicting policies arising, for example, as side-effects of adaptation interventions. Networks may help cut across dysfunctional formal relationships or support the formation of coalitions for change and, where trust is sufficient, push for collective action on adaptation.

Local management of natural resources remains an important element for maintaining the resilience of social-ecological systems. Community-based natural resource management remains crucial to maintaining ecosystem services because state agencies do not have the resources, reach or skills to be as effective as the people and groups with a long-term stake in adaptation and sustainability. Local knowledge is also important to adaptation in local social-ecological systems (Lebel et al. 2013). Gender relations are also critical, as women often have less access to water for agriculture than men. As economic development proceeds and technological opportunities for rapid exploitation expand, some balance between top-down and bottom-up governance initiatives is often needed to adaptively cope with new dynamics and pressures. Polycentric architectures may then be appropriate.

Efforts to make governance more inclusive and adaptive in the water sector will need to take into account the diversity of political systems in developing countries. In some states, downward accountability of authorities is primarily through elections. In other states, leaders and institutions such as the military or single political parties play dominant roles (Malayang, Wasson and Tay 2009). Non-state actors have an important role to play in exploring the alternatives in development, and in pressing for decision-making that is more inclusive and adaptive. Many examples in this chapter have underlined the agency of non-state actors, without dismissing the ongoing importance of the state in adaptation (Jordan and Huitema 2014). At the same time, improvements to water governance alone can only do so much; fundamental institutional and democratic deficits set significant limits.

Scholarly debate on effective water governance in a changing climate can be grouped under three competing perspectives. The positivist perspective sees the challenge as being primarily one of having a good process and institutional design; with these in place, progress towards governance that supports local social-ecological systems will follow. The sceptivist perspective sees the challenge as being primarily about differences in power, which are hard or impossible to redistribute. Institutional reforms and multi-stakeholder processes, while attractive on paper, are resisted, circumvented and recaptured by those holding more power. The third, a realist perspective, lies somewhere in between the other two, recognising the relative balances of power but confident that progress can be made under favourable circumstances and with compromises.

The framework used in this study to organise the findings is consistent with a realist perspective: it pays attention to the potential of an appropriate institutional architecture to support fair allocation, without ignoring issues of agency beyond the state, the heterogeneity of interests in the political economy of water, and the importance of informal and formal accountability mechanisms. Although the framework was developed to focus on earth system governance issues (Biermann et al. 2010) that are multilevel and include agreements among states, this review shows it is also useful for work with a bottom-up approach.

This review and the evidence upon which it is based have some limitations. On the one hand, many studies infer the need for particular changes in governance based on failures of existing systems to have features that, as theory suggests, are important for adaptation and fairness. On the other hand, evidence that including such a feature makes a difference is limited mostly to pairwise comparisons of cases which in reality differ considerably. A few studies have worked with larger samples of cases, allowing some statistical analysis. But these in turn suffer from lack of nuanced metrics that are comparable across many studies. Almost all studies focus on indicators of capacity and not direct measures of impact; thus much uncertainty still remains in trying to measure performance. Overall, direct inferences about how specific features of governance systems influence outcomes of interest—like the resilience of local social-ecological systems—are difficult to draw. There is still a need for further research in most propositions on what improves the performance of water governance systems.

Nevertheless, the combination of theory, reasoning and empirical evidence suggests promising ways forward. Improving water governance so that local social-ecological systems are more resilient to climate change and other stresses in the context of developing countries will most likely involve the following five points.

- Ensuring decentralisation reforms are accompanied by mechanisms to maintain effective vertical and horizontal coordination.
- Improving the accountability of authorities at all scales through multiple formal and informal mechanisms.
- Improving procedures to enhance local representation in deliberations over water decisions so that water allocations are fair and access is just and gender-sensitive.
- Increasing the flexibility of rules and procedures and expanding opportunities for social learning so that changes and surprises may be dealt with more effectively.
- Acknowledging the important role that non-state actors and social networks have in water governance. In particular how they help empower those who are most vulnerable, or can help monitor and expose the influence of powerful, narrow and vested interests.

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Chapter 7
Governance for Water Security and Climate Resilience in the Tonle Sap Basin

Sam Sreymom, Pech Sokhem and Ky Channimol

7.1 Background

This empirical assessment of water and climate change governance conducive to water security and climate resilience in the Tonle Sap Basin builds on the literature review presented in the previous chapter. Having looked at the current state of knowledge, the aim of this chapter is to seek ways to improve water governance and determine how local social-ecological systems are and can be resilient to climate change.

Governance is complex and therefore difficult to capture in a simple definition. In general it is understood that the need for governance exists anytime a group of people come together to accomplish a common organisational and societal goal. Here, we focus on how the quality of institutions, organisations and processes can be improved to enable actors to collaborate or interact across diverse sectors and multilevel governance structures in building response capacity to cope with the impacts of natural and human system changes to achieve water use efficiency and more equitable, reliable access to sufficient water resources (Institute on Governance 2015).

"Governance determines who has power, who makes decisions, how other players make their voice heard and how account is rendered" (Institute on Governance 2015). Governance is not only the structures and institutions including the rules and procedures articulated in law and policy, or social norms and organisational goals and strategies of the state and actors whose activities are supposed to be guided by the institutions they participate in (Young 2000a), but also the quality of informed participation, shared decision-making and implementation, accountability and learning (Pech 2010).

7.1.1 Governance in water security and resilience

The global focus on water security accentuates the need as never before for integrated and adaptive approaches to water management, including agricultural and environmental sciences, water resources engineering, environmental policy and law (Cook and Bakker 2012). Water security, especially freshwater for agriculture, fisheries and livestock production, and household use, is the single most important component for food security. It safeguards individuals and communities, particularly subsistence farmers and fishers, dependent on rain-fed agricultural systems and natural resources for their livelihoods (UNDP 2013).

Adaptive capacity is a significant factor that can help build resilience and reduce vulnerability. Adaptive capacity refers to the ability to manage and influence resilience to physical changes (irrigation, dams and infrastructure development), social and human system changes (water use and management systems) and changes in natural systems (water flows and rainfall distribution) that affect water availability and demand (Eastham et al. 2008). As such, adaptation has become an increasingly important response and resiliency strategy to natural disasters and climate change.

The Earth System Governance Project, a 10-year research program, is organised around five analytical problems: the architecture of earth system governance, agency beyond the state and of the state, adaptiveness of governance mechanisms and processes, their accountability and legitimacy, and modes of allocation and access in earth system governance (Biermann 2007, Biermann et al. 2009 cited in APN 2011). In addition, the research strategy emphasises four crosscutting themes that are crucial for the study of each analytical problem and for the integrated understanding of earth system governance: the role of power, knowledge, norms and scale (APN 2011).

At international level, establishing the principles for better global natural resource governance is often contentious. However, the core principles for good water governance set out by the United Nations Development Programme (UNDP 1997) are universally recognised (Graham, Amos and Plumptre 2003). The Asia-Pacific Network (APN 2011) principles of good water governance and principles for social-ecological resilience (Simonsen, Biggs and Schlüter 2014) build on these. As seen in Table 7.1, when grouped into themes, these principles often overlap. How well they perform in practice is determined by social contexts. Importantly, these principles consider both the results of power and how well power is exercised (Institute on Governance 2015).

Table 7.1: Principles of water governance and resilience

UNDP principles of good water governance	APN principles of good water governance	Principles for social-ecological resilience
1. Legitimacy and voice • **Participation**: all men and women have a voice in decision-making, directly or through legitimate intermediate institutions • **Consensus orientation**: mediate differing interests to reach a broad consensus • **Informed decision**: leaders and the public have a broad and long-term perspective and adaptiveness **2. Performance of institutions and processes** • **Responsiveness**: try to serve all stakeholders • **Effectiveness and efficiency**: produce results that meet needs while making the best use of resources **3. Accountability** • **Accountability**: decisions are accountable to the public, as well as to institutional stakeholders • **Transparency**: processes, institutions and information are directly accessible to those concerned, and enough information is provided to understand and monitor them **4. Fairness** • **Equity**: all have opportunities to improve or maintain their well-being • **Rule of law**: legal frameworks should be fair and enforced impartially • **Conflict management**: effective prevention and timeliness	**1. Architecture** • Interplay and coordination • Fit between institutional architecture and social and ecological systems **2. Agency** beyond the state and of the state • Capacities and structures of governance • Resources and access to information and expertise • Cooperation and inclusiveness of non-state actors **3. Adaptiveness** of governance • Flexibility • Learning **4. Accountability** mechanisms and processes and legitimacy • Upward and downward • Transparency and monitoring **5. Allocation and access** modes of in earth system governance • Procedural justice • Outcome justice **Four crosscutting themes** • Power • Knowledge • Norms • Scale	**1. Participation and responsiveness** • Maintaining diversity and redundancy of actors, knowledge systems, cultural groups, species, and landscapes **2. Connectivity and linkage of systems** • Managing connectivity and interaction of components of social-ecological system to ensure recovery from disturbance • Managing slow variables and feedback to ensure social and ecological systems remain configured and functioning and keep pace with rapid changes in the world • Fostering complex adaptive systems thinking to comprehend the dynamic connections, independencies and complex interactions within the system to enhance the resilience of the system **3. Adaptiveness and learning** • Encouraging learning to improve diversity of knowledge and experimentation of management and adaptation • Broadening participation from all stakeholders to build trust and legitimacy for decision-making **4. Polycentric governance** • Promoting polycentric governance systems, which consist of diverse governing bodies to enhance collective action in responding to change and disruption

Sources: Institute on Governance 2015; APN 2011; Graham, Amos and Plumptre 2003; Simonsen, Biggs and Schlüter 2014.

7.1.2 Research questions

This chapter addresses the key research question: What is the current situation of water and climate change governance and how can existing institutional arrangements and interactions be improved to cope with changes in natural and human systems that affect water security? Specifically, it seeks to answer the following subquestions:

- What are the governance responses, including institutional arrangements, policy responses and capacity development, to changes in water resources, and what is the adaptive capacity and resulting vulnerability?
- How can governance be made resilient and what is the deviation or divergence from resilience theory and experiences of other countries.
- What conditions will characterise an efficient, equitable and sustainable water resources governance system and resultant vulnerability/adaptive capacity across time and levels of water management?

7.1.3 Approach and scope

Primary data was collected from key informant interviews (KIIs), focus group discussions (FGDs) and researchers' observations in three communes, one in each study catchment. FGDs and KIIs were held with members from two farmer water user communities (FWUCs) in each selected commune, and also with community leaders (local state, non-state and informal actors) in all three catchments. The aim was to solicit their viewpoints on the current state of governance and ways for improving its relevance in scope, scale and quality.

The communes and FWUCs were selected based on geographical and topographical considerations and their vulnerability to extreme climate events, particularly flood and drought.

In Chrey Bak catchment, Kompong Chhnang province, KIIs and FGDs were held with members of Trapang Trabek FWUC in Kouk Banteay commune and Taing Krasang FWUC in Taing Krasang commune, and commune councillors and local people of Kouk Banteay commune. These two FWUCs, along with two community-based organisations (CBOs), were chosen because they have been affected by water conflicts. Kouk Banteay commune was selected because it lies midway between the plateau and Tonle Sap floodplain. This geographical position is important because communities on the floodplain are more likely to suffer from flood than drought, while the opposite is true for those on the plateau.

In Pursat catchment, Pursat province, KIIs and FGDs were held with members of Damnak Ampil FWUC in Lolork Sar commune and Kampang FWUC in

Svay Dounkeo commune, and with commune councillors and local people of Samraong commune. Damnak Ampil and Kampang FWUCs were selected because of their upstream and downstream locations. Samraong commune is located in the upperlands some 30 km south of Pursat main town, and has a distinctive geography. The area suffers frequent mountain or flash floods and droughts. In the dry season and during dry spells in the wet season, the commune often faces water scarcity, making it an apt choice for our study of local adaptive capacity to climate extremes.

In Chinit catchment, Kampong Thom province, KIIs and FGs were held with members of Stung Chinit FWUC in Kompong Thmor commune and Roluos FWUC in O'Kanthor commune, and with commune councillors and local people of Thnaot Chum commune. Stung Chinit is one of the few irrigation schemes in the country which mainly operate on gravity and where the FWUC can collect irrigation service fees. In Roluos irrigation scheme, private water providers are involved in water distribution. Thnaot Chum commune is flooded for most of the wet season.

The study findings and recommendations were presented at provincial workshops with participants from affected villages, communes and districts, and at a national workshop with participants from provincial and national agencies from multiple sectors (water, agriculture, forestry, fisheries, environment and disaster management) and provincial governments.

7.2 Findings and implications

The results were interpreted and analysed using the analytical framework developed by the Earth System Governance Project: architecture, agency, accountability, allocation and access, and adaptiveness. The content of each theme was modified slightly to fit the current situation of Cambodia and to facilitate the use of information and data.

7.2.1 Architecture

The architecture for environmental and water governance is explored from an institutional perspective including the sets of rules and procedures articulated in law and policy, or social norms, with a focus on the arrangements for state and non-state actors, and informal organisations.

7.2.1.1 Current governance responses – institutions

From the review of national strategies, policies and statements, it is clear that the government has made a strong commitment to address the impacts of natural hazards by ratifying international conventions and by adopting and implementing key strategic plans and policy documents.

A range of strategies and initiatives has evolved to respond to climate change, including a Climate Change Investment and Expenditure Fund, the Cambodia Climate Change Strategic Plan (CCCSP) and 15 sectoral climate change strategic plans. Measures have also been taken to improve cross-sectoral and interagency coordination, public participation and the harmonisation of internationally funded activities.

Cambodia clearly acknowledges that a "business as usual" approach to the challenges of climate change is simply not enough. This is evident in the prioritisation of sectoral adaptation strategies, for instance. However, mainstreaming climate change adaptation into national development planning requires not only well-elaborated rules, norms and policies, but also strong political commitment and concerted national and regional efforts backed by institutional, technological and human resources, which are often in short supply.

With the adoption of the CCCSP in 2013, climate change responses are being implemented across multiple sectors such as water, agriculture and disaster management. This raises the question whether climate change adaption should be integrated into existing development plans; and if not, where it would best be implemented as a stand-alone plan. There are also questions concerning the costs of implementation.

Despite the investment in developing strategic plans, there is limited evidence of significant mainstreaming of climate resilience and disaster risk reduction in planning and investment decisions at national and subnational levels. Rectangular Strategy Phase III 2014-2018, for example, recognises "the issue of management of environment and natural resources, and climate change and its impacts on Cambodia's ecological system and socio-economic development, as one of the key challenges to be addressed in a collaborative and cross-sectoral manner" (RGC 2013a, 10). Yet there is no specific national policy for dealing with climate change or for mainstreaming disaster risk into development planning in a coherent manner (MOE 2014). The National Strategic Development Plan (NSDP) 2014-2018 admits that even at the highest policy level, calls to make action on environmental and climate change issues a core priority in development framework have gone largely unheeded. The Plan calls for accelerated efforts to "save the Tonle Sap (and other water systems) and forests for sustainable livelihoods of people in rural areas, and sustainable agriculture" (RGC 2013b).

7.2.1.2 Interplay and coordination

It is important to consider interactions between institutional arrangements and governance architectures in two ways: coherence between strategies, policies and their implementation processes; and coordination among key agencies (Young 2002b).

In Cambodia, as far as policy coherence and consistency are concerned, several components of various sectoral development strategies, action plans and programs have been adopted and are at different stages of implementation with varying levels of performance. The most relevant ones are outlined below.

Box 7.1 National and sectoral strategies and action plans for climate change adaptation, disaster risk reduction and sustainable development

Cambodia National Environmental Action Plan 1998-2002
National Strategic Plan on Green Growth 2013-2030
National Strategy and Action Plan 2014-2016: Mangroves for the Future
Strategic National Action Plan (SNAP) for Disaster Risk Reduction (DRR) 2008-2013
Cambodian Climate Change Strategic Plan (CCCSP) 2014-2023
Sectoral climate change strategic plans (for 15 sectors) (2013)
National Report for Rio+20 United Nations Conference on Sustainable Development 2012
Rectangular Strategy for Growth, Employment, Equity and Efficiency Phase III 2015-2018
National Strategic Development Plan 2014-2018
Industrial Development Policy 2015-2025: Market Orientation and Enabling Environment
National Water Resources Policy (NWRP) (2003)
National Strategy on Rural Water Supply, Sanitation and Hygiene 2011-2025

From the review of these strategic documents and plans, some critical observations stand out:

- Most of the strategies, action plans and programs, especially for crosscutting sectors, were developed in response or reaction to the pressure to meet international obligations, and formulation processes were often donor-driven. As a result, once a donor-funded activity came to an official end, there was little follow up by designated national agencies.

- Climate change, biodiversity and environmental sustainability issues are crosscutting in nature, but responsibility for their management is often divided up between multiple agencies, leading to jurisdictional overlap between ministries.
- Strategies and action plans are generally implemented through different arrangements, often in the form of interministerial committees, councils and secretariats anchored in lead ministries. Yet limited human and financial resources and a lack of proper management tools to ensure functionality and accountability constrain their effectiveness and sustainability. Oversight agencies often have relatively weak capacity to manage budget allocation and ensure continuous compliance, coordination and monitoring.
- Many crosscutting strategies and action plans have limited success, both during implementation and follow-up. Reasons include weak financial, technical and management capacities, too many priorities, unrealistic or unattainable goals, a lack of trust, poor coordination and collaboration, and institutional jealousy.
- In some instances, evaluation is left to national monitoring and evaluation (M&E) and planning systems.

7.2.1.3 Fit between institutional architecture and systems

Many scholars have argued the importance of achieving an adequate fit between institutional arrangements and the sustainability of social-ecological systems (Young 2002a; Folke et al. 2007; Ostrom 2010). A good fit is expected to strengthen the capacity of societies to manage resilience. The discourse on water security and water governance management in Cambodia and in the Tonle Sap subcatchments must consider numerous interests and differentiated perspectives, especially:

- multijurisdictional: responsibility gaps and overlaps between several national ministries and line agencies;
- multiscale: multiple interests at household, village, community, subcatchment, basin, national and regional levels; and
- multiperspective: different economic, political and social objectives, unequal power relations and imbalances in financial and technological capacities between subnational agencies (Pech and Sunada 2006).

A growing body of literature recognises the increasingly important role of informal organisations, local authorities and community groups in "building community resilience to adapt to, cope with and recover from climate shocks" in the Mekong region (see, for example, Bui et al. 2013).

Integrating climate change adaptation into water resources development and management will require a shift from the current predominant top-down and highly centralised approaches. Yet deconcentration and decentralisation (D&D) reform with increased autonomy of the provinces, districts and communes, all of which conduct their own development planning that feeds into national planning, has been slow to unfold (MOE 2012).

7.2.1.4 Unfit between needs, capacity and willingness

Financial resource constraints

Devolution of government powers from central to subnational levels has so far bought about limited change to governance structures. Although D&D has paved the way for clearer definitions of subnational administrations' functions and responsibilities, they have not been matched with the necessary financing.[1] Nearly 93 percent of national expenditure planning takes place at the central level, with little input from local governments about what is needed and how much funding is required (UNDP 2013). The Commune/ Sangkat Fund (CSF) accounted for only 1.6 to 1.7 percent of national spending between 2008 and 2010, an average of USD20, 000 per commune as of 2011, while the share of provincial spending was just 3.7 to 4.9 percent. These figures are barely sufficient to meet communes' basic development needs, let alone their financing needs for adaptation (UNDP 2013).

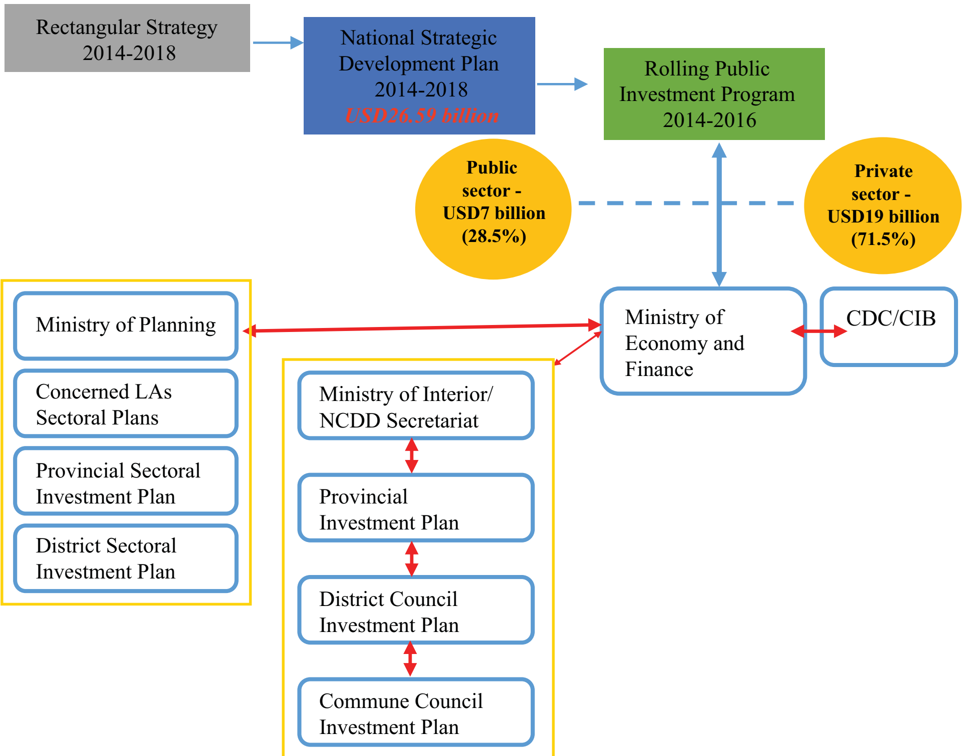
Figure 7.1 illustrates the subnational planning process within the overall national development and planning framework. Planning is aligned with commune councils' five-year mandate. A better structured mechanism to support subnational administrations' financial, institutional and technical planning is beginning to emerge. This mechanism is set out in the 2010-2019 National Programme for Sub-National Democratic Development. Even so, the mobilisation of funds for subnational adaptation and development planning remains constrained by several factors. These include the quality of the commune investment plan and mismatch between the resources available through national and subnational development frameworks and the project priorities proposed under the CSF.

The national planning framework is complex and seems to parallel the planning processes of the sector ministries and their line departments and district offices, though with limited synergies.[2]

1 Key informant interviews with district and commune councillors.

2 Key informant interviews with subnational administrations and communities, 2014 and 2015.

Figure 7.1: National and subnational planning processes within national development framework



Source: Pech 2015

Subnational administrations have too few financial resources, and this situation is likely to continue for the foreseeable future. Still, they are to set aside some of those funds for local adaptation measures aligned with their respective development plans. By introducing the discretionary District/ Municipality Fund, the National Programme for Sub-National Democratic Development envisaged increasing financial autonomy for districts. Yet the amount of financing is set at USD40, 000 per district, or less than USD1 per capita (UNDP 2013).

Institutional capacity and human resources constraints

Interviews and discussions revealed the view that there are significant shortages of institutional and human resource capacity at the subnational level to plan, design and deliver public services for resilience building. This suggests there is much scope to incorporate climate change risks in investment planning and implementation at commune, district and provincial levels. If the technical and institutional capacity for supporting climate-resilient livelihoods is not enhanced as an integral element of planning, programming, budgeting and execution, it is likely that a significant opportunity for introducing resilience at the subnational level will be lost (MOE 2014).

These findings concur with the Cambodia Climate Public Expenditure and Institutional Review (Bird et al. 2012), which found that climate change adaptation capacity and awareness at subnational levels is low compared to the national level. This is because investment, capacity building and awareness-raising initiatives have been pursued mainly at the national level. Identified capacity gaps at subnational and national levels include:

- Limited planning capacity and awareness of climate change and its impacts at the commune level.
- Limited capacity of authorities at provincial and especially district level to support commune needs.

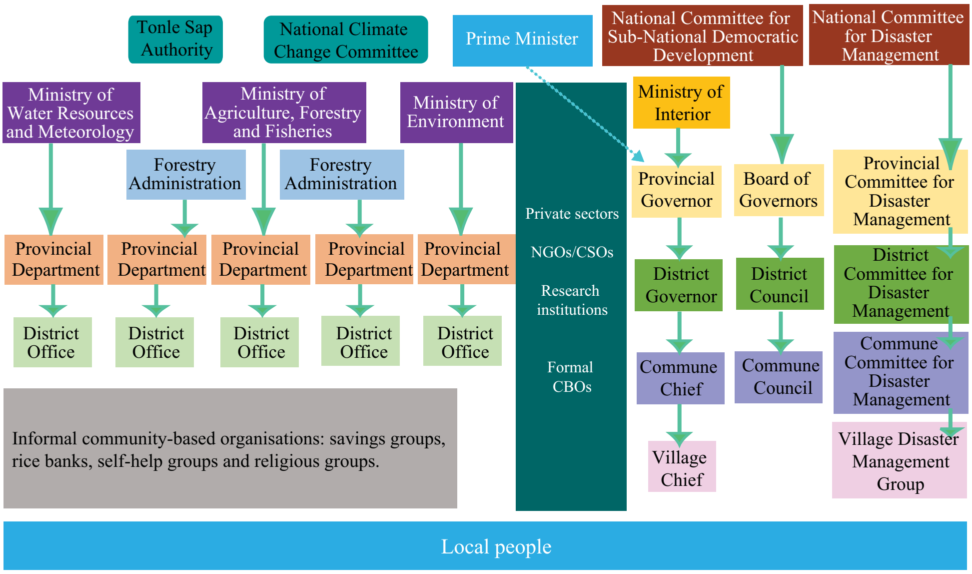
The MOE has acknowledged that limited coordination and cooperation due to a lack of communication and information sharing among government agencies is a barrier to climate change adaptation. Other obstacles are limited technical and financial capacity and a lack of knowledge (MOE 2014). Importantly, the outcomes, outputs and impacts of major investment projects at all levels, including at commune level, should be monitored and evaluated.

7.2.2 Agency 'beyond the state'

Cambodia's political regime is made up of legislative, executive and judiciary branches; and the country is divided into 24 provinces, Phnom Penh municipality and 26 cities/krongs. There is a two-tier administrative arrangement: national and subnational. An assortment of non-state actors, formal state agencies, formal organisations and informal associations are involved in water governance and adaptation. The study looked at organisations or arrangements of state, non-state actors and informal organisations whose activities are supposed to be guided by the rules of the institutions in which they participate (architecture), and quality of decision-making, enforcement/compliance and monitoring.

In the context of climate change, water governance actors at national and subnational levels consist of two main bodies: state and non-state actors, and informal agencies. As seen in Figure 7.2, most of the ministries and agencies involved have provincial and district offices which should allow them to interact closely with the local communities they are supposed to serve (Pech and Sunada 2006).

Figure 7.2: Actors in water governance and climate change



Sources: Pech 2015; interviews 2014-2015

7.2.2.1 State actors

Local state actors fall into four main categories: province or municipality, district, commune and village. However, in the Constitution and in the Law on Administrative Management (Organic Law), villages are not mentioned.

Village level

Village authorities are the lowest administrative level in Cambodia. Village chiefs perform two main roles; they report to commune, district and provincial councils, and head the Village Disaster Management Group (VDMG). The VDMG is part of the national disaster coordination mechanism and reports to the Commune Disaster Management Committee, the District Disaster Management Committee, and the Provincial Disaster Management Committee (CPDMC). VDMGs normally consist of six to ten members who are often men in their early 30s and 50s. Interviews suggest that VDMGs play an active role mainly in emergency response to floods, droughts, storms and disease; they

- work with the Provincial Department of Water Resources and Meteorology (PDWRAM), and coordinate local interventions by political parties in drought years to pump water onto fields to irrigate rice crops;
- serve as emergency personnel to help evacuate villagers and organise search and rescue operations in times of flood; and
- facilitate emergency relief distribution.

VDMGs are clearly not equipped to play a major role in climate change adaptation and resilience planning. Apart from disaster response, they also help families affected by domestic violence and those who have lost their homes to fire (reported in KIIs and FGDs).

Village authorities are expected to contribute to local development planning including the five-year Commune Development Plan (CDP) and annual Commune Investment Plan (CIP). The village chief collects information about the development priorities in the village and files a report with the commune council, which then selects the priorities to be included in the CDP and CIP.

Interviewees and discussants reported attempts by villages to have the construction of roads and irrigation canals included in village development planning, suggesting the potential for integrating adaptation in local planning. Few villages had been successful in securing funding, however. There were some reports of a focus on soft adaptation measures such as raising awareness, improving understanding and changing attitudes and practices in relation to climate change

Commune level

There are two main commune authorities: the commune council and the Commune Committee for Disaster Management (CCDM). The commune council is one administrative level higher than the village.[3]It consists of a commune chief, two deputy chiefs and a number of councillors. According to the 2001 Law on Commune and Sangkat Administrative Management, the commune council is tasked with supporting national policies, representing the state and addressing basic local needs such as security and public order, essential public services, general well-being, and social and economic development. The commune council also has responsibilities to preserve the environment (including climate change and water security), address conflicts and respond to local needs (Niazi 2011).

Commune councils prepare annual development plans and investment plans as part of a structured mechanism to support the administration of the CSF;

3 An average commune council consists of 8 to 15 permanent members. Unlike the provincial, district and village councils, the commune council is not a state-appointed agent. The first direct commune council elections in February 2002 marked a significant development in the country's history (Kim and Henke 2005). Ideally, commune council members are elected directly by local voters based on individual merit. In practice, candidates stand on a party ticket (Kim and Henke 2005). This creates divided loyalties as most if not all council members think and act primarily along party political lines rather than in direct response to voters' demands.

they are also responsible for mobilising financial and technical resources to implement local development projects (UNDP 2013).

The CCDM consists of village chiefs, local school heads, religious leaders, respected community elders and police chiefs, and is chaired by the commune chief. They develop and facilitate community-led contingency and disaster risk reduction plans, though their focus is on responding to disasters and providing relief to affected households.

District level

District authorities are the second highest subnational authority after the provincial level. District chiefs perform two main functions: chair of the district council, and chair of the District Committee for Disaster Management. With respect to disaster management, district authorities serve as a hub for disaster information collected from village and commune authorities and relay it to the PDMC.

Provincial level

Provincial-level state actors are the highest subnational administrative authority. Organisational structures and lines of reporting are complex; they encompass:

- the provincial administration, commonly known as the Provincial Committee, chaired by the provincial governor and several vice-governors with membership from technical and sectoral departments, security and armed forces;
- the PDMC, chaired by the provincial governor with membership from relevant departments, armed forces, police and military police;
- the Provincial Rural Development Committee, an important platform for collaborative planning and management among line ministries and government agencies, private sector, civil society, national and international development agencies;[4] and

4 The Provincial Rural Development Committee is composed of the provincial governor, deputy governor, directors of the Department of Rural Development and Planning, directors from technical departments, and district chiefs. Oversight for the committee's day to-day execution of annual work plans and budgets is undertaken by an executive committee comprising the governor, deputy governor, directors from the departments of Rural Development, Planning, Economy and Finance, Agriculture, Forestry and Fisheries, Water Resources and Meteorology, Women's and Veterans' Affairs, the director of the provincial treasury, and the chief of the Local Administration Unit (Niazi 2011).

- provincial departments and district offices (25 in total), though these are more inclined towards vertical coordination with central-level ministries and agencies.

In the event of an extreme climate event, the PCMD coordinates emergency response along with provincial line departments to help local communities. Typical interventions include pumping flood water from fields to save rice crops and distribution of rice seed.

Provincial line departments can and will continue to play an important role, in longer term adaptation strategies if they have access to the necessary human and financial resources to perform their duties directly, in line with their mandatory functions under D&D reform.

National level

Parliament (National Assembly and Senate) holds legislative authority. Members of the National Assembly are selected through an electoral process, and the executive branch of the government is led by the prime minister assisted by deputy prime ministers. The government consists of 25 ministries and two secretariats of state. In each ministry there is one minister, several secretaries of state and undersecretaries of state, and several departments and offices.

Ministries that are responsible for water governance and climate change in Cambodia include the Ministry of Water Resources and Meteorology (MOWRAM), Ministry of Environment (MOE), Ministry of Agriculture, Forestry, and Fisheries (MAFF), Ministry of Rural Development and the Ministry of Energy and Mines. Other national government bodies include intercommittees and agencies, the most relevant of which is the newly established National Council on Sustainable Development (NCSD).

The main role of the NCSD is to promote a more sustainable future by achieving a balance between the economic, social, environmental and cultural dimensions of development. It comprises 28 ministries and state secretariats, the Supreme National Economic Council and the governors of 26 municipalities and provinces. It also encompasses several interministerial committees including the Council for Agricultural and Rural Development, Cambodia National Mekong Committee, National Committee for Disaster Management (NCDM), National Committee for Sub-National Democratic Development (NCDD) and the Council for the Development of Cambodia (CDC). The NCSD replaces the former National Climate Change Committee and the National Council for Green Growth.

The Ministry of Interior (MOI) has jurisdiction over provincial and district levels of government, and all provincial and municipal governors are accountable to the MOI.[5] The MOI's Department of Local Administration and Provincial Offices of Local Administration are responsible for supporting provincial, district, commune and village authorities in their planning and budgeting.

Jurisdictional overlaps, in-fighting among ministries and interministerial committees, and a lack of effective communication and feedback mechanisms, mainly due to sectorally specialised divisions, hamper synergies between ministries. Limited information flows due to poor communication (horizontal and vertical) among central ministries, local authorities, agencies and local communities, and between line ministries and subnational departments, as well as lack of adequate financial and human resources, were also confirmed as barriers (MK16 2013).

7.2.2.2 Non-state actors

Non-state actors include civil society (NGOs, CBOs), private sector, academia, research centres, formal and informal associations.

The CBOs most relevant to water governance and climate change in this study are farmer water user communities (FWUCs), fisheries communities and forestry communities. FWUCs were created to help promote farmer-led irrigation management and development. However, according to key informants, many of the FWUCs established by projects or by communities themselves are either not fully functional or not financially sustainable.

Key informants reported that some national and local NGOs are working on climate change adaptation in the water and agriculture sectors. They have disseminated practical knowledge on how to adapt to climate change and variability through training on selecting and growing new rice varieties, rainwater harvesting, animal raising, water and soil conservation and home gardening. Some local NGOs also provide support to help local communities deal with longer term trends that may affect different aspects of local livelihoods, and build on existing social economic and political assets to improve adaptive capacity. Their work includes the provision of agricultural extension services, establishment of savings groups and rice banks, rehabilitation and building of small-scale irrigation and water supply structures, and helping diversify income-generating activities. They have also provided some training to local help/volunteer groups on emergency

5 Many provincial governors are also advisors to the prime minister or government, allowing them to sometimes bypass the MOI and report directly to top levels of government (personal communication with members of government 2015).

response. From an adaptation perspective, these activities are essential in helping local people to secure their livelihoods and improve local adaptive capacity.

Private sector and vested interest groups include hydropower developers, sand mining operators, economic land concessions, mineral exploration and exploitation concessions, and private companies. The role of these players is becoming increasingly important. There is a growing interconnectedness among domestic and international private investors which gives then considerable influence and power; and these interest groups often align with people in positions of high authority.

There are some private companies with permission from PDWRAM and municipalities to provide irrigation water services directly to farmers. For example, in Roluos of Chinit catchment, people have to pay USD123 per ha per three-month cropping season. Where capacity to convey water to rice fields is limited by the canal system and pumping facilities, the private company has played a very important role in supplying water to the rice fields that the Roluos scheme cannot reach. The company has also contributed in building roads.

Emerging informal organisations include savings groups, rice banks and groups for animal raising and vegetable growing. The FGDs revealed that the presence of such informal organisations provides local farmers important support to recover from natural disasters. Box 7.2 outlines the processes for, and advantages of, establishing a local savings group and a rice bank. The critical advantage of the local savings group was how it enabled farmers to avoid selling their farmland during periods of family sickness, crop failure or because of natural disasters. The same was true for the presence and operation of the rice bank, whereby local farmers could continue farming in the event of crop failure due to flood or drought. The rice bank provided loans in the form of rice not just for the purpose of food but also for seeds for the next planting or to replace damaged crops. A farmer discussion group suggested that these informal organisations help strengthen recovery and promote resilience.

> If it were not for those activities [savings group and rice bank], some of the local farmers would face an extremely tough time trying to recover. When crops fail we don't know where to turn. Luckily we have them, and we can borrow from them, take the rice seed and pay later. (FGD, Pursat, 2015)

Box 7.2: Local mutual-assistance through a savings group and a rice bank in Chrey Bak catchment

Savings group

The savings group was established by Prasak Microfinance in 1996. At the outset, Prasak Microfinance provided credit of USD50 (about KHR200, 000) to each member who then had to contribute KHR200 per month to the bank. Although the project completed in 2004, the savings group continued. It currently has 634 members (414 women), and 12 committee members (4 women) including a chair, vice president, secretary, accountant and cashier.

Members can get interest-free loans to cover the costs of basic needs; otherwise, the interest rate is 3 percent a month for loans taken out to finance business and house construction, for example. Participation is essential to the success of this local savings group. A main problem is insufficient budget. It has been suggested that better-off group members save more money to help poorer members.

Rice bank

The rice bank was established by Kongry Organization in 2007 with a total fund of USD400. It allowed villagers to take over 10 kg of rice at the beginning of rice transplanting and to return this post-harvest with a small additional premium of 3 kg. The premiums have sustained the rice bank and provided the poor with access to seeds that they would not otherwise have been able to afford in such quantity. The community uses the rice bank not only for farming, but also to meet food needs. It has 82 members and is managed by a six-member committee. All of the committee members are women including the chair, vice president, accountant and cashier. Remarkably, the bank has reportedly never faced any problems or challenges.

Source: Commune Councillor, Kompong Chhnang province, July 2015

Interviews with villagers revealed that while the savings groups and rice banks have been particularly useful in times of crop failure or family sickness, the animal raising and vegetable growing groups have not been sustained. This is due to a general lack of confidence on the part of local farmers when it comes to the potential for profitability and certainty regarding market access.

Other non-state actors include local religious groups and pagodas. The case study of Kompong Chhnang confirmed the significant role of groups comprising clergymen, elders, monks, respected teachers and local opinion-makers in providing disaster emergency response to flood victims. The study also revealed that they are highly relevant to the general effort to strengthen local social networks and enhance a sense of belonging and build community capacity to respond to climate change. These groups work effectively through joint or individual networks to raise funds from villagers and other donors for and during religious ceremonies, and from the PDMC.

It was observed that groups of local and non-local actors, including political party representatives, are highly visible, especially during election campaigns. Political parties sometimes operate alongside, and often in place of, formal state institutions to improve the provision of public services in their constituencies, using government and their personal resources or means. In times of crisis, for example, they assist in disaster response by providing irrigation pumps and emergency relief, hoping for voters support at the next election. They also finance small to medium scale infrastructure development such as irrigation canals, roads, bridges and schools. However, it was reported that political parties' assistance or response was often biased and targeted mostly their supporters and relatives. It was not provided to all people, leading to feelings of discrimination and division among local communities and households. This raises concerns about maladaptation, as well-intended but poorly designed infrastructure interventions can lead to adverse residual impacts: overall risk is not reduced, but simply transferred or shifted elsewhere.

7.2.2.3 Interface: vertical-horizontal synergy

Water governance and climate change require a high level of coordination and cooperation, both vertically and horizontally, between and among institutions, be they state or non-state agents, formal or informal organisations. In the study sites, however, there has been strong domination by state actors and political elites from the capital cities. This is also evident among government ministries, agencies and organisations. For instance, there is extensive mainly top-down vertical interaction between central agencies and local departments and offices. Figure 7.2 depicts a very strong top-down sectoral or isolated line of command, and weaker horizontal communication and synergy. The horizontal structures refer to interaction and communication among sector ministries, departments and offices at the same level of administration.

At the local level, there are parallel approaches to community-based water management; for example, the creation and management of agricultural cooperatives by MAFF and its provincial departments, the fisheries communities by the Fisheries Administration, forestry communities by the Forestry Administration, and FWUCs and river basin committees by MOWRAM and PDWRAM. All of these were established and are regulated by different laws, national agencies and subnational sector agencies. Moreover, the MOI and NCDD deal with local democratic process, while the NCDM and the Red Cross deal separately with disaster risk management at the local level (MK16 2013).

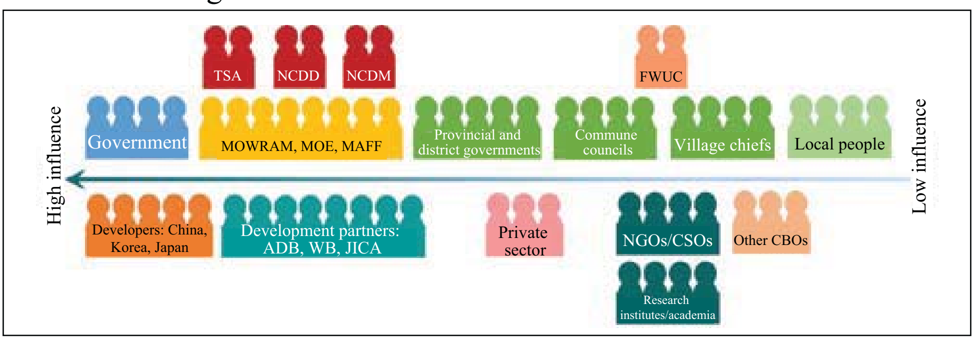
It was observed that commune councils do not have actual decision-making power despite the promise of D&D. The root causes for the lag in the devolution of functions and powers may include lack of financial resources, constraints in capacity, vested interests and institutional jealousy.

Figure 7.3 depicts the growing informal influence of private investors. Most of these are influential due to their financial power and connections, either having political alliances with top decision makers, being a member of the Senate, or by being both financier and developer of the project or concession (MK16 2013).

The position of civil society organisations (CSOs) in such power and risk-sharing relationships is very low. CSOs can potentially hold more influence if particular processes are secured and maintained (e.g. through close partnerships with relevant actors) and if they possess adequate financial and technical resources. The opportunity and challenge for NGOs and their role in climate change adaptation is that their interventions are often based on short project cycles and the objectives and agendas of their donors. Moreover, there is an element of suspicion between government institutions and NGOs, as seemed evident during discussions on the 2015 Law on Associations and NGOs.

Currently, there is a significant lost opportunity as adaptation services continue to be provided in an uncoordinated and piecemeal manner (UNDP 2013). It is not uncommon that an NGO promotes technical assistance to improve agricultural productivity in villages where agricultural lands are entirely rain-fed; or that PDWRAM rehabilitates or extends tertiary irrigation networks where the commune lacks sufficient technical assistance to promote multicropping on newly irrigated land.

Figure 7.3: Power and influence of actors in water governance and climate change



Sources: Interviews 2014-2015; MK16 2013

Networks of actors at subnational level seem to be in place, and these can be further strengthened to support communities and villagers to become resilient to climate extremes. Findings indicate the importance of rebuilding kinships and social connections among villagers as the basis for adaptive capacity and resilience at local level, and preserving and strengthening these networks. However, when crises and the scale of adaptations needed for risk reduction exceed local ability to cope, local farmers tend to wait for assistance from the authorities.

Village groups and local villagers are repositories of indigenous knowledge about people, community and traditions—geography important for quick and effective decision-making in an emergency. Indeed, their involvement in the designing, planning, implementing and monitoring of climate change adaptation and local development is critical.

There are still needs for identifying local priorities and concerns, assets and resources to build local adaptive capacity; for a comprehensive disaster risk management program especially early warning, preparedness, response and recovery; and for mainstreaming climate risks into local development plans and anticipating long-term trends and abrupt changes in climate. Moreover, people at local and subnational levels need to be empowered to play their roles effectively and efficiently. The next section examines those factors facilitating or impeding responsive and accountable governance and the potential for improved management of water security and climate change in the study sites.

7.2.2.4 Constraints faced by local actors

The study reveals complex matters of local agency and leadership at different levels of government and governance. The village level appears to lack leadership and initiative in tackling current climate change variability and long-term climate change; for example, village councillors felt that they were not empowered to pro-actively plan for or cope with the extreme and abnormal events associated with climate change and were instead dealing with the aftermath reactively.

> I don't know what really to do until the disaster [drought] happens, then we will intervene by helping farmers pump water to save their crops. (Village chief, Pursat)

In terms of leadership action, the village chiefs tend to be preoccupied with the management of village affairs such as domestic violence and animal vaccination, and coordinating microdevelopment projects. The issues of climate change adaptation seemed far removed from their day-to-day concerns and were certainly not an immediate priority.

Interviews revealed that local farmers generally tend to rely heavily on the state and political parties for development actions and climate change adaptation. Personal leadership, bold initiative and ownership seem to have been eroded by decades of civil war, especially by life under the Khmer Rouge regime. During that time people had little choice but to entrust and follow the instructions of their *angkar* (leader/authority).

Some local informal associations and initiatives such as rice banks and savings groups have been emerging. However, they are new and only capable of addressing some minor aspects of adaptation and resilience. Sustained support to improve local leadership initiative and ownership should be considered before addressing area and context-specific adaptation.

Commune councillors and CBO leaders exhibited some sense of leadership in local efforts to adapt to climate change. These were, however, reactive, private and spontaneous, with limited anticipation and planning elements. They can only finance small development projects proposed by villages, and have to actively seek financial and technical assistance from NGOs, development agencies, political parties and district or provincial authorities.

7.2.3 Adaptiveness

Adaptiveness relates to governance regimes' capacity for regulatory flexibility and continuous learning (APN 2011). Given the many uncertainties involved in development planning to bring climate change considerations into water and disaster management, policies, projects and strategies must be built on best available knowledge in context and improved periodically. The need for greater adaptiveness is especially evident in the study catchments due to relatively low adaptive capacity, in particular the poor state of knowledge, inadequate technical capacity and limited institutional innovation.

7.2.3.1 Flexibility

From our assessment, many finance, water, environmental and climate change institutions (the architecture) and organisations (agency), at both national and subnational levels, are particularly rigid and not well suited to an adaptive governance approach. Lack of flexibility is associated with the current top-down arrangements and intolerance of requests for change, often considered a challenge to authority. Another important constraint evident in the study sites is lack of resources; practical implementation of adaptations requires adequate financial and technical capacity, as well as sufficient, accessible climatic and hydrological data.

There is some evidence of commitment to adapt including the development of a more strategic vision. Leaders and the public have some general understanding and a broad long-term perspective on good governance and human development. Nonetheless, there is evidence of gaps between strategic vision, policy and actual implementation. At the national level, for example, there is no clear linkage between different policy and strategic documents, or between policy and implementation. This lack of coherence and consistency affects governance performance and responsiveness. Institutions were not seen as trying to serve all stakeholders, and processes were not seen as effective and efficient in meeting the needs for strengthening community livelihoods and resilience. Rather, they were seen as entrenching existing power structures.

Effective M&E provides feedback on implementation, thus allowing for adjustments that are characteristic of flexible and adaptive water management. This also permits learning from past successes and failures to improve future implementation (Folke, Colding and Berkes 2002). Current institutional arrangements, however, do not seem to exhibit this kind of flexibility; M&E and feedback mechanisms are limited. Although disaster plans do include recommendations to put such mechanisms in place, the focus still seems to be limited to financial and technical support.

7.2.3.2 Learning

Ability to learn and willingness to improve understanding appear to be low: even though key government strategic and planning documents including Rectangular Strategy III and NSDP 2014-2018 have called for incorporating climate change into planning, the study found no evidence of efforts to do so.

As regards capacity to learn from climate change experience, local water managers and climate adapters can be grouped into three categories—provincial line departments and district authorities, CSOs and NGOs, local authorities and local people—each with varying degrees of capacity to learn or understand.

Provincial departments exhibit a certain capacity to learn, at least from their empirical observations and experience, and try to respond to the need for sustainable livelihoods and resilience. However, translating their strategies into better performance and programs is being stymied by complex political process concerning the delegation of functions, decisions and finance, the mismatch between mandates and resources and deviation from the promise of local autonomy and its reality.

Commune and village authorities have a similar capacity to observe and make judgements about disaster risks and climate change vulnerability. They have not, however, had the opportunity to learn and act proactively on them. Interviews with permanent members of the Commune Disaster Management Committee suggest that the committee tends to function more like a crisis response centre, which acts only when there is a disaster.

Local people also have the capacity to learn from experience and respond to climate change, particularly related effects on water resources including extreme events such as flood and drought. Those who are affected by seasonal floods have adapted well. They know when flooding usually occurs and prepare by stockpiling additional food, boats and medicines. In the event of an extreme flood, they also expect disaster relief from various institutions. Regarding agriculture, farmers have adopted appropriate farming methods to adapt to extreme events and weather variability including irregular and shifting patterns of rainfall; this change is categorised as autonomous adaptation. They also assist village authorities by identifying needs and priorities to be incorporated into the CDP and CIP. These requests often include water infrastructure, an important planned adaptation. However, climate change responses including autonomous and planned adaptations are affected by other factors including market access, personal experience, and the varying levels of support provided by different institutions.

7.2.4 Accountability – mechanisms, processes and legitimacy

The assessment looked at accountability as an important element for ensuring legitimacy of governance processes, determining compliance and effectiveness of rules, and promoting adaptability, flexibility and learning.

7.2.4.1 Upward and downward

Accountability refers to the “responsibility of one party for their use of authority over another party” (Chheat et al. 2011). From evidence gathered from the field study, literature review and observations, accountability stands out as one of the major areas in need of immediate improvement. Decision-making, whether by government, the private sector or even CSOs is not yet really inclusive or accountable to the public.

Public accountability mechanisms at national and local government levels are weak and substantially undermine regulatory compliance and policy effectiveness. Interaction and communication between central ministries, local authorities, agencies and local communities is primarily top-down. And horizontal communication and accountability among line ministries, subnational departments and subnational administrations or councils require much improvement (UNDP 2013). Low levels of interaction and joint-participation between stakeholders may be caused by a lack of appropriate capacities, a misallocation of available resources, and/or a lack of mutual trust between national and subnational offices (World Bank and Asian Development Bank 2006).

Subnational accountability is integral to D&D, and district and commune councils know they are accountable to local people (Chheat et al. 2011). Subnational representatives and local people acknowledged that some local accountability is present, but with limitations. Subnational governments try to respond to local people's needs and help them in times of disaster through mobilising various supports from national government and development partners, CSOs and NGOs, though with limited success.

> The commune watched the rising water level and disseminated information to people in villages … During the flood, the commune organised boats to rescue victims. We also have pagodas and schools we can use as temporary shelters for flood victims. (Commune chief, Kampong Chhnang)

At scheme level, FWUCs' responsiveness to their members is constrained by a lack of financial resources. This is partly because of the difficulty collecting, or farmers' reluctance to pay, irrigation service fees (ISF) for unreliable irrigation services, and also due to an absence of promised government financial support. From the six FWUCs interviewed, only Chinit, Roluos and Trapang Trabek were supported through the collection of ISF and able to respond to community needs. FWUCs that do not collect ISF must depend entirely on the subnational government.

The same situation applies to financial reporting. Those who have collected ISF have filed financial reports and submitted these to their members, the commune, district office and PDWRAM. All FWUC members were informed about the status and activities of their respective FWUCs through village meetings or village focal persons.

FWUCs have limited power to enforce compliance with FWUC rules and regulations, and have to rely on the support of local authorities. Only one FWUC reported that its respective subnational government did not cooperate well in helping them collect ISF and address conflicts.

Two-way accountability seems to work better through a market mechanism. A few private irrigation water services have entered into water delivery agreements with farmers. The private company at Roluos scheme provides assurance that water will be delivered on time and that any crop loss due to lack of water will be compensated. In return, farmers must pay the water delivery fees without fail.

In summary, most respondents felt that equity in which all men and women have opportunities to improve or maintain their well-being, has not been achieved, and that the rule of law, where legal frameworks are fair and enforced impartially, is not firmly in place.

7.2.4.2 Transparency and monitoring

Most respondents considered that issues of participation, inclusiveness, transparency and openness were particularly important, as some types of actors, especially at the subnational level, have been marginalised.

The assessment found that transparency is constrained by a poor free flow of information (disclosure) and a lack of proper inclusiveness of all stakeholders. Processes, institutions and information were not directly accessible to all concerned; only limited information was provided to interested stakeholders and was often difficult to understand and monitor.

Information related to water resource management and climate change adaptation is mainly available at the national level. It is very important that information on water availability for each catchment and how to adapt to climate change be shared, particularly with local communities and authorities. However, the stickiness of institutional information flows and a "closed" information culture stifle the sharing of information and, consequently, the transfer of knowledge for innovation. There is also a physical lack of data collection and data management facilities.

Observed and modelled water balance estimates to better manage water in each catchment have not yet been made available to local communities to help them identify suitable adaptation measures. Although many adaptation strategies have focused on agriculture and water, in practice they have only reached a limited number of local farmers.

7.2.5 Allocation and access

The importance of individual and household access to financial, technical and natural resources, institutions and due process is a major finding identified by the study. Access to institutions and processes has a profound influence on fairness and material and spiritual satisfaction, and also determines the capacity to adapt, cope and recover from climate shocks and disasters.

Field data indicates that local communities generally lack essential resources to help them adapt to climate change. Access to physical assets such as irrigation and drainage infrastructure was limited, preventing local communities from adapting effectively to climate risks. Even in study sites that have access to irrigation, communities still face problems of unequal access to water. Those who farm land near the main canal and at the head and tail ends enjoy plentiful water supply, while those whose land is far from water distribution points always suffer uneven water distribution. This was reported in all six schemes.

The water balance calculations presented in Part 1 indicate that only Chrey Bak has sufficient water resources to meet current demand. Even so, access to water for some communities and farmers in the catchment remains problematic. Water allocation and water-use efficiency in all three catchments are hampered by inadequate distribution systems, unlevelled fields, distance from water sources and distribution points and absence of a proper water allocation mechanism.

In Chinit catchment, for the commune in the vicinity of the forest, the situation was different. Lack of access to water during drought and limited livelihood options often forced villagers to exploit timber and non-timber forest resources, or sell their labour to forest companies. In an average year, such activities account for up to 50 percent of their income. In bad years, when extreme climate events destroy their crops, the villagers focus entirely on forest product extraction. This autonomous adaptation puts more pressure on rapidly declining forest cover, and is considered a maladaptation.

Some villagers have accessed microfinance loans, local savings groups and local rice banks to help them respond to extreme climate events. However, those that did not and who had limited financial resources were forced to sell land or other property or migrate to cities or neighbouring countries.

Table 7.2: Identified resource needs

Resource	Description	Access and situation
Physical	Irrigation schemes, canals, water storage facilities	Poorly designed, too few schemes, limited water storage structures
Natural	Water, forest, fisheries, agricultural inputs, land fertility	Limited or restricted access, declining quantity and quality, inequitable distribution
Social	Local associations, e.g. savings groups, rice banks, and collective action	Limited but its emergence is a positive sign for climate change adaptation
Human	Extension and consultation	Limited but better than before due to more support for capacity building
Financial	Resource contributions for better adaptation and governance	Limited but climate financing is in place

The study finds that shortages of production inputs such as fertiliser, water and labour, and limited access to favourable input and produce markets, contributed to the underlying vulnerability of farmers. The study also reveals insufficient technical knowledge to respond to climate change. While there is some training and dissemination of technical knowledge, local people still find it hard to do more to address climate change due to their limited understanding of the issues affecting them and a lack of financial support.

Extension services are generally understaffed and are primarily only available at the provincial level. Their outreach is limited and farm mechanisation, fertiliser use and affordable farm credit are all suboptimal (UNDP 2013).

7.2.5.1 Procedural justice

Procedural justice, discussed in Chapter 6, refers to "the fairness of rules and process to reach decisions" which can be obtained through "quality participation and deliberation". At catchment level, FWUCs deal with fair access to water by engaging local and provincial authorities to help resolve any disputes over water allocation and use. They attempt to identify solutions through a meeting between FWUC members, authorities and local farmers. Not all schemes use this mechanism, however. At the national level, to ensure equity and fairness, policies emphasise the representation of stakeholders, especially local communities, though policy implementation has so far been limited. Private sector involvement in providing local communities with affordable and timely water supplies is helpful in that it brings more plots of land within reach of a reliable water supply. But collaboration between private businesses and FWUCs is not yet fully developed. According to a representative from Roluos scheme, the FWUC and the private company do not work together to organise water delivery coverage. Rather, the company seems to work more closely with PDWRAM and provincial authorities.

Fair access to resources also depends on local collaboration. For example, constraints due to topography can affect even distribution of water to all plots and lead to head-tail discrimination. Head and tail-end water users need to be collaborative in sharing water, but they do not always act collectively. In Stung Chinit and Damnak Ampil schemes, farmers in the head and tail-end reaches try to keep water within their plots; despite many negotiations, the issue has not yet been solved. Also in Stung Chinit, water distribution would be more equitable if farmers raised earth bunds. However, they do not do this because they are not interested in rice farming due to soil infertility.

Local communities' participation in decision-making about climate change adaptation seems to be very limited. They have been invited to identify their needs but tend to focus only on water structures, considered a long-term climate change adaptation. Since commune authorities have only just been trained and informed about climate change, there are no specific adaptation objectives or targets in development planning.

The extent of participation in local decision-making varies between different administrative levels; and local adaptation decisions that are made are often not implemented. It is perceived that men and women have the opportunity to participate and express their voice in decision-making directly or through legitimate intermediate institutions via development of the CDP, CIP, disaster management and risk reduction plans. However, evidence of meaningful mediation of different interests to reach consensus on the best interests and effective policies and procedures appears limited. This is especially true when considering the complex crosscutting sectoral and jurisdictional, and overlapping vertical and horizontal forms, of water management.

7.2.5.2 Outcome justice

To improve justice within water governance, water rights can be significantly enhanced through the provision of comprehensive water infrastructure. Many projects related to water and infrastructure management still face problems of inequitable access to water, due to either physical or institutional constraints. Irrigation projects do not ensure equitable water distribution among all farmers. Incomplete infrastructure causes conflict in water sharing and uneven water distribution, as has been clearly shown in Stung Chinit and Damnak Ampil schemes. Institutional arrangements for improving water allocation and access need to be both functional and more flexible to evolve with change.

7.3 Improving governance for water security and climate resilience

Good practice principles and important characteristics for supporting climate change adaptation and water governance seem to be in place, but there is room for significant improvement. Mainstreaming adaptation into development has been promoted. Even so, the actual integration of climate resilience and disaster risk reduction into national and local development planning and practice has often been hampered by a complex array of governance challenges. This chapter has identified some of the key issues besetting the effective application of the principles of good governance as a building block for adaptive governance.

Architecture

- Strategies, policies, action plans and programs often list broad strategic directions and action plans. These could have been more effective had human, technical and financing capacities been considered and steps taken to build local technical, administrative and managerial capacity. Importantly, there needs to be more emphasis on continuously learning and improving from M&E.

Agency

- Many institutions for climate governance have already emerged beyond the state and beyond the formal setting. However, horizontal coordination and collaboration between them is limited. This means building or improving synergies between different non-state agencies.
- National-subnational coordination is still top-down as D&D in Cambodia has been slow to unfold. Despite some progress, further devolution of powers from central government is lagging.
- Building community resilience means supporting the capacity of subnational authorities, especially locally elected councils, and CBOs in the planning and implementation of water security and climate resilience measures.
- Mutual support groups such as savings groups and rice banks play a central role in rebuilding a sense of community and self-reliance, traditional sources of social capital that were eroded under the Khmer Rouge. With more attention and support, these informal groups can set a firm base to build resilience through adaptation.
- A variety of actors are actively involved in water governance, climate change adaptation and disaster risk reduction at multiple levels, and government has supported the adoption of a plethora of national water management and climate change policies. However, the interplay of different legal and governance structural aspects for coordination and collaboration among a range of diverse agents has been constrained by institutional pride and jealousy, a piecemeal sectoral approach, donor-driven priorities, little institutional ownership, minimal follow-up actions, and limited financial, human and technical resources.
- There is a misfit between institutional architecture and the ecological system. Sustainability, environmental protection, biodiversity conservation, climate change adaptation, water security—all are crosscutting topics by nature, but are subdivided among many ministries and their subnational departments, leading to responsibility overlaps and gaps. Despite good intentions to foster inclusion and engagement, institutional integration remains wishful thinking, stymied by jealously guarded "old" powers and a pervasive silo mentality making it hard to resolve structural weaknesses.

Adaptiveness

- Finance, water, environmental and climate change institutions and organisations at national and subnational levels are still too rigid, making them impenetrable to adaptive governance approaches.

- The need for greater adaptiveness is especially evident in the study catchments due to relatively low adaptation capacities resulting from a lack of knowledge and limited technical and institutional capacity.
- A flexible regulatory approach is constrained by top-down structures and intolerance of difference or change.
- Implementation of adaptive governance features requires adequate financial and technical capacity, as well as sufficient, reliable and accessible climatic and hydrological data.

Accountability

- Top-down decision-making and accountability still dominate planning processes and constrain access to institutions, reliable information and new knowledge. This emphasises the need to consistently communicate information about decision-making structures and decisions made.
- Two-way dialogue with institutional stakeholders and the public should be promoted and accountability mechanisms including credible M&E put in place. All men and women should have a voice in decision-making about matters that concern them, either directly or through legitimate intermediate institutions that represent their interests. Good governance mediates differing interests to reach broad consensus.

Allocation and access

- Unequal allocation of and access to limited resources constrains adaptive capacity and climate resilience.
- Water resource management in the face of climate challenges necessitates consideration of both sides (supply and demand) of the water balance, putting greater emphasis on equity, distribution and efficiency.
- Fair allocation of and equitable access to livelihood resources requires participation of all people but especially of local communities and the most vulnerable populations.
- Access to appropriate knowledge can be improved by establishing information platforms and a variety of communication channels to keep information flowing to all stakeholders.

7.4. Recommendations and future research

The following recommendations draw on the results of our analysis and valuable discussions during consultation and dissemination workshops with a broad range of stakeholders at multiple governance levels.

- Pay more attention to supporting no-regret adaptation measures to turn them into important and cost-effective mechanisms for building community resilience.
- Restore social capital—personal leadership, bold initiative, self-reliance, community-mindedness, innovation and ownership—through a revitalisation approach to rebuilding traditional institutional structures all but eliminated by decades of civil war.
- Support informal mutual support groups such as savings groups and rice banks to set solid foundations for building a stronger sense of community and self-reliance.
- Encourage "learning to improve" by providing further technical and financial support to communities and commune councils. This would cultivate knowledge diversity, experimentation and innovation. And by building the trust needed to improve the legitimacy of knowledge, it would broaden participation in decision-making to build water security and climate resilience
- Build disaster risk management capacity and secure adequate resources for a comprehensive disaster management program including early warming dissemination, preparedness, response and recovery; for mainstreaming climate risks into local development plans; and for funds mobilisation.
- Explore innovative finance approaches such as private sector finance for adaptation and climate investment funds, and include inclusive and sustainable growth priorities in the current national budget allocation and development framework.

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Chapter 8
Synthesis – Vulnerability and Adaptation Assessment and Ways Forward

Pech Sokhem, Chem Phalla, Sam Sreymom

8.1 Vulnerability and adaption strategies

This study has examined various aspects and elements of vulnerability and resilience such as the frequency and magnitude of floods, droughts and other disasters. It has also considered population density, changes in land use, impacts of poverty on coping capacities, access to early warnings, mutual help groups and community-based initiatives.

The core chapters examined changes in water demand and availability due to climate change and economic activities; adaptation capacities based on levels of poverty, knowledge and willingness to adapt; and governance and the capacity to manage adaptation and resilience. Findings have been reviewed and integrated into the overall vulnerability and adaptation (V&A) assessment framework. Financial assets have also been included in the assessment since they are among the most important resources.

8.1.1 Background and approaches

It is evident from global reports that greenhouse gas emissions will continue to grow over the next few decades (IPCC 2007). It is also clear from the water balance assessments in Chapters 2-4 that hazards and risks associated with more extreme weather patterns will continue to increase. In addition, more localised changes in ecological systems and the environment being caused by human activities are contributing to the socioeconomic vulnerability of households and communities and will further compound potential sensitivity to climate hazards, socioeconomic conditions and adaptive capacities at all levels.

The site- and context-specific V&A assessments were undertaken to provide Cambodian and international organisations and stakeholders with information to better identify, design and implement new programs and mobilise potential funds. The assessments also revealed the need for additional information to identify targeted adaptation actions which can reduce vulnerability and increase resilience.

A multi-aspect assessment of climate vulnerability looks at the impacts of climate variability and change in conjunction with the socioeconomic characteristics of the systems, the effectiveness of related policies and institutions and the types of coping strategies, among a range of other factors. In this analysis, vulnerability is assumed to be related to poverty and limited access to the following livelihood assets:

- Natural assets. Including reliable access to livelihood resources such as land and water, and the quantity, quality and timeliness of availability and access to key natural resources.
- Physical assets. The basic infrastructure and key social facilities needed to support livelihoods such as reliable irrigation systems, roads, schools and medical facilities, access to energy and markets, and domestic water supply and sanitation.
- Social and political assets. The relationship between business and government institutions, traditional cultural and familial bonds, local networks/associations and the ability to influence policy decisions.
- Human assets. The quality of human resources including education and capacity, communication and information exchange.
- Financial assets. Per capita community investment budgets in the national budget and financial sustainability of community-based organisations.

Each aspect of the asset is assessed against performance criteria such as quality, quantity, effectiveness and sustainability, including the ability to respond and/or recover during future changes.

Table 8.1: Ranking of key assets

Score	
1	Significant gaps exist relative to basic good practice—quality, quantity, effectiveness and sustainability
2	Most relevant elements of basic good practice have been undertaken, but there are some significant gaps
3	Most relevant elements of basic good practice have been undertaken, but there are a few significant gaps
4	All relevant elements of basic good practice have been undertaken and in one or more cases exceeded, but there are one or more significant gaps in the requirements for proven best practice
5	All relevant elements of basic good practice have been undertaken and in one or more cases exceeded, and there are no significant gaps at all

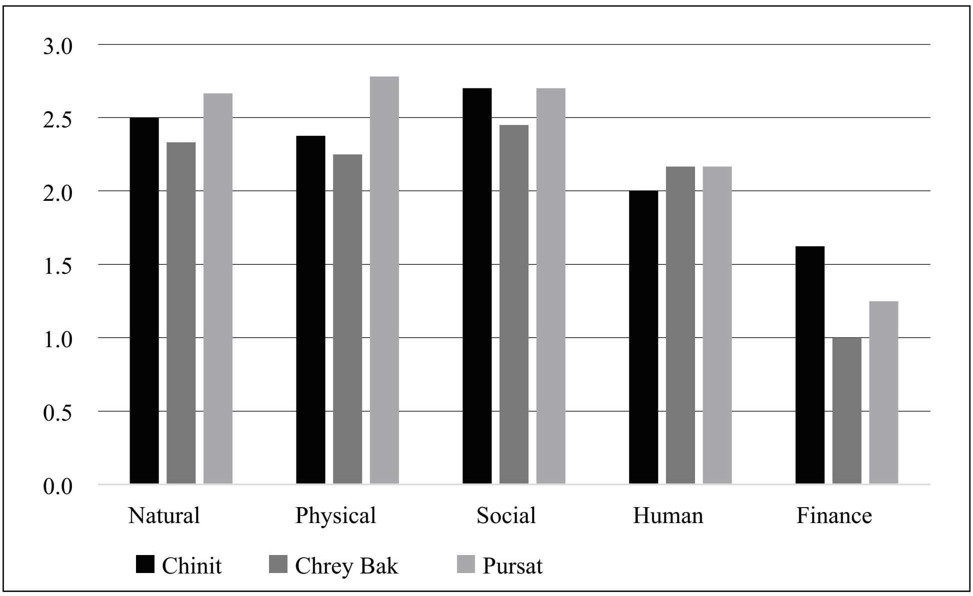
8.2 Indicators and indices used to measure and monitor vulnerability

The following sections discuss the results of performance indicators for access to key assets that either positively or negatively affect capacity to cope with, adjust to and recover from climate events, shocks and trends. The assessment combines five indicators reflecting key assets and 17 aspects including availability, access and trends. Indicators are a useful tool for measuring, monitoring and communicating the vulnerability of a system and seeking solutions. The study team were well aware that expressing system vulnerability by means of too few or too simplistic indicators can produce invalid results. And given that vulnerability is a site- and context-specific phenomenon rather than a generic condition, this assessment considered a complex array of livelihood assets and aspects at local scales and networks of processes that shape local vulnerabilities (Barnett et al. 2008).

8.2.1 Overall assessment results

The vulnerability of communities in the study sites is expected to further increase due to their strong dependence on water, land and forest resources. Substantive projected increases in climate change-related impacts, relatively poor water governance and limited resilience strategies further compound potential shocks and risks in the study areas. This will very likely result in additional challenges for the governance capacity of traditional state structures.

Figure 8.1: Overall scores for key assets to support adaptation and resilience



As shown in Figure 8.1, all three catchments score low to medium on a scale of 1 to 5. This indicates that most required assets are in place; however, there remain significant gaps in quality (e.g. suboptimal public participation), quantity (e.g. inadequate funds, human resources), effectiveness (e.g. low performance of measures taken) and sustainability (e.g. low resources allocation).

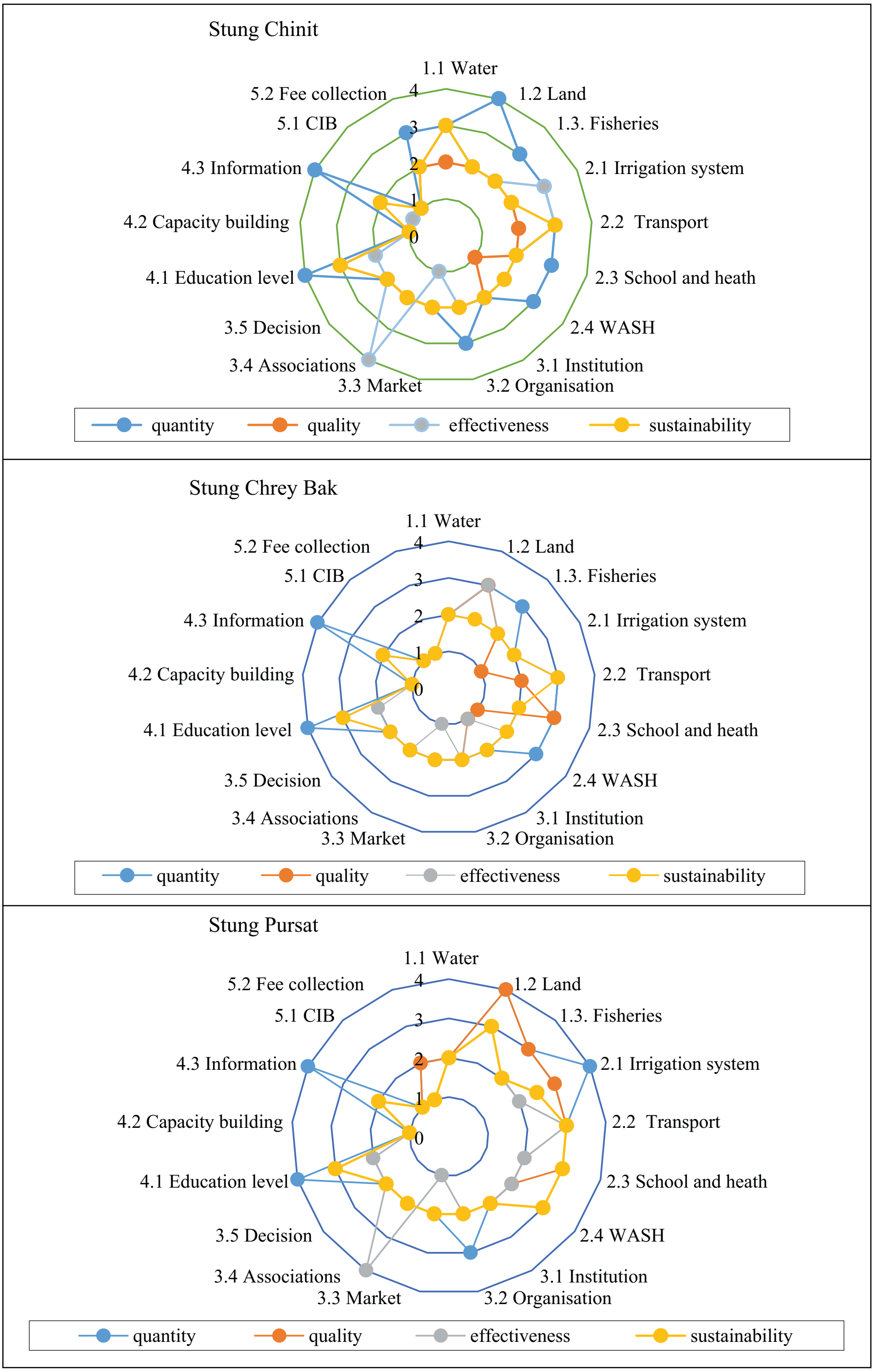
Financial assets scored lowest in all three catchments. As indicated by the results of the participatory assessment presented in Chapter 5, the commune budget remains extremely low at around USD1 per commune member, and most farmer water user communities (FWUCs) are unable to collect irrigation service fees. Farmers and irrigation water users complained about poor irrigation reliability and felt that water should be free. Stung Chinit irrigation system performs better in that users are willing to pay water fees because the FWUC meets most water demands. But the situation for Stung Chinit catchment as a whole is much less promising.

Human assets have the second lowest score for all study areas. Measurements include qualified human resources, access to capacity building, and knowledge transfer. All had low levels of information regarding early warnings and weather forecasts for water allocation plans, crop calendars and resilient crop selection.

8.2.2 Availability of and access to key assets

A detailed look at the 17 aspects evaluated in the assessment and illustrated in Figure 8.2 shows how all three catchments share similar climatic and environmental challenges and asset poverty, particularly lack of financial and human resources. The five assets are discussed in more detail in the following sections.

Figure 8.2: Scores for key aspects to support adaptation and resilience



Note: CIB: community investment budget, WASH: water, sanitation, and hygiene

8.2.2.1 Natural assets

Land and water were considered as the two key natural assets and included use for domestic, industrial and environmental needs.

As far as water is concerned, Stung Pursat continues to face water security issues despite relatively higher investment in water storage, reservoirs and irrigation systems. Statistically, water resources seem to be available to meet demands in many schemes of Stung Pursat (Chapter 4) due to dam regulation. In reality, however, access to water for some communities and farmers could continue to be problematic because of a lack of proper irrigation infrastructure, the distance of farmland from water sources and a lack of proper water allocation among users (MK16 2013).

In Pursat, the results of the water balance assessment show that water availability will be too low for farming requirements, even in current conditions, as the demand for irrigation is already higher than water availability in the dry season. It is therefore probable that some crops will not receive water at the critical time. Critical periods for rice growth, for example, include the reproductive and ripening phases. A disruption in irrigation can reduce crop yields and increase the risk of crop failure (IRRI 2007).

Water security in Pursat is further threatened by:

- over-expansion of both wet and dry season paddy rice fields;
- ongoing and planned water diversion to neighbouring catchments;
- increases in the unpredictability of water availability at some times in some locations;
- increases in irrigation areas exceeding the availability of water, coupled with diversion loss from evapotranspiration (ETo) rates and poor quality distribution canals;
- absence of key information to support water allocation and water use planning; and,
- lack of proper mechanisms (river basin organisation, river basin planning) for water allocation and regulatory enforcement.

Stung Chrey Bak scored the lowest with regard to water security as the river almost disappears during the dry season. Local communities face water shortages for consumption and irrigation during both the dry season and in parts of the wet season. To date, there has been no substantial investment in any major water structures except for wooden and temporary structures built mainly by local communities and the Provincial Department of Water

Resources and Meteorology (PDWRAM). The poorly perceived schemes initiated during the Khmer Rouge period from 1975 to 1978 have not been adequately operated and maintained.

As discussed in Chapter 3, it is expected that Stung Chrey Bak is going to face serious water issues resulting from increases in both the magnitude and frequency of flood and drought. These environmental issues are aggravated by the lack of investment in restoring aging systems, a lack of proper water allocation and inadequate planning.

With respect to effective water management, including quantity, quality, effectiveness and sustainability, Stung Chinit seems to score better than other catchments. This is a result of gravity-based irrigation systems providing a relatively reliable water supply for farmers in three irrigation schemes. However, as outlined in Chapter 2, problems remain for the other 47 schemes. Overall water security in Stung Chinit is threatened by expanding irrigation systems, climate change and the poor design and maintenance of reservoirs. In addition, soil fertility issues are reducing rice productivity. Significantly, the development of 17 irrigation schemes in the upstream area of Pursat is also expected to cause considerable water shortages in Stung Chinit, putting tremendous pressure on water distribution and water quality in the catchment.

All three catchments face constraints over land resources with farmers facing a reduction in cropping areas resulting from increased family size, land sales to alleviate poverty and costs associated with family health issues (RGC 2012). Natural resource constraints are being compounded by climate change (as floods and droughts intensify) and poor governance. The increased frequency and magnitude of peak flows and consequent flooding will potentially damage housing, infrastructure, crops and economic assets.

8.2.2.2 Physical assets

Physical assets are categorised as irrigation systems, transport and road access, school and health facilities, and access to water supply and sanitation.

In access to key infrastructure, Stung Pursat scores slightly higher than the other two catchments. This is due to multimillion dollar investments in irrigation and hydropower dams and irrigation and water diversion canals. Stung Chhrey Bak scores the lowest for irrigation and water storage structures.

All three catchments score poorly when it comes to proper operation and maintenance of infrastructure. They also fail to mainstream climate resilience in drainage and storage capacity designs, and during heavy flooding water infrastructure generally suffers significant damage. Moreover, water resources are not planned and developed in an integrated and informed manner, resulting in suboptimal use and unsustainable development.

As regards access to key social facilities including schools, health care and key emergency or disaster relief facilities, such as flood havens and relief distribution routes, the communities living in remote upper catchment and mountainous areas tend to have the lowest access. These difficult-to-reach areas have received the least attention and support because they are not readily accessible by decision makers and development agencies (Chapter 7)

Even though the participatory assessment results (presented in Chapter 5) show that there is no problem concerning water for domestic use, water quality remains paramount to human health and ecosystem productivity. It therefore remains important to improve household access to water by reducing travel times and to ensure water quality for health reasons. The government's (RGC 2012) sustainable development performance report noted that health shocks are a major source of vulnerability for the poor who tend to have a higher incidence of injury and illness. Significant challenges include the nature of their work which is often associated with greater risk, relatively poor food security and nutrition, a lack of access to improved water supply and sanitation, and limited access to health and social services. Illness or injury often means lost income and/or savings or selling off assets. Around 40 percent of cases of families losing land involved health crises (RGC 2012).

8.2.2.3 Social and political assets

Social and political assets include access to, and quality of, institutions and organisations (architecture and agency), markets (for buying and selling products) and microfinancing or credits, social networks and associations, as well as the ability to influence policy decisions.

Social and political assets in all three catchments need to be significantly improved. These assets determine the inclusiveness and responsiveness to local needs for investments in physical assets such as irrigation structures, dams and general infrastructure development.

Social coherence is also likely to be affected as downstream-upstream water conflicts intensify, especially during severe drought. Reduced food availability and competition for limited resources can also trigger social conflict and mass displacement of populations. The risk of social unrest and displacement is expected to worsen under future climate conditions. Increases in the frequency and intensity of climate events such as storms, floods, droughts and heat waves will ratchet up the direct threats to lives and livelihoods and heighten the incidence of infectious diseases (IPCC 2007). Higher temperatures will affect vector biology and increase the concentrations of water and air pollutants. The health consequences of climate change include increased endemic morbidity/mortality due to malnutrition, diarrhoea, respiratory diseases, heart attack or heatstroke, and other infectious diseases (IPCC 2007).

Good governance at all relevant levels is considered to be one of the main factors for ensuring the ability of households, communities and catchments to adapt to, cope with and recover from changes and shocks induced by climate variability and change (Walker et al. 2004). However, as outlined in Chapter 7, poor quality governance and challenges to resilience were observed in all three catchments and are evident across Cambodia.

Institutional arrangements at the national and subnational levels remain sectoral, and ministries tend to operate in a compartmentalised manner. Local governance is weakened by a lack of proper delegation of power and resources. Integration is a recurrent and fundamental challenge for pursuits of sustainability where bureaucracies are fragmented by ministerial lines and agencies (Chapter 7).

8.2.2.4 Human and financial assets

The analysis of financial and human assets for all three catchments indicated multiple problems. A recent assessment shows that the current knowledge for informed decision-making and related technical and scientific capacity is inadequate (MOWRAM and MOE 2013). Effective agricultural and irrigation planning, flood protection and management, reservoir design, hydropower planning, road design, drainage planning and many other activities require accurate, reliable quantitative information. Skilled human resources are also hard to find, both at the national and subnational levels (MOWRAM and MOE 2013). The lack of or poor access to these key human and financial resources presents one of the biggest challenges affecting adaptive capacity and drastically increases potential vulnerability.

8.3 Adaptation and development

Communities in the three catchments are primarily agrarian and their adaptation capacity is relatively weak. Local people's livelihoods and the natural resources they depend upon are highly susceptible to climate variability and/or extreme climate events and other human-induced change.

This vulnerability is expected to further increase due to local people's high dependence on natural resources. The vulnerability assessment based on the availability of and access to natural resources, as well as trends in changes and shocks, can provide a useful snapshot of vulnerability. It can be used as a spatial or temporal tool to identify relative vulnerability across provinces at different times, determine vulnerability hotspots and inform adaptation planning and design.

Analysing the relationship between the causes and effects of climate change, together with changes in the economy and social welfare, helped to illustrate the following;

- It is clear that without addressing water security and climate resilience, it will be difficult to achieve food and energy security, environmental sustainability and poverty alleviation—some of the country's key development goals.
- In addition to climate change, hydropower projects, irrigation dams and economic activities such as forest conversion and floodplain changes cause changes in water availability, affecting farmers and water users in the catchments (Keskinen et al. 2011).
- To help communities cope with and recover from the impacts of current and future challenges, it is necessary to urgently improve the physical and economic management of water by providing access at the right time, location, quantity and quality. This must be undertaken in conjunction with the mainstreaming of climate resilience into national and local development goals.

8.3.1 Natural physical assets

It is important to manage key natural and physical assets by improving access, availability and long term sustainability:

- Climate change adaptation and disaster risk reduction cannot be undertaken in isolation from the strengthening of integrated water resource management, or without addressing the vulnerability of communities with low adaptive capacity.
- Hard infrastructure and technological interventions such as dams, reservoirs, canals, pipelines and pumps should be implemented alongside political and institutional reform of water management and governance, access and distribution, with detailed attention to their long-term sustainability (operation and maintenance budget, human resources).
- Farmers and water users need to improve agricultural water management by reducing irrigation water loss especially during the dry period. Moreover, determining suitable cropping patterns is also helpful for safe and sound water resources allocation. The Department of Water Resources

and Meteorology, Department of Agriculture and FWUCs should play an active role in the provision of technical assistance to farmers and in conflict management.

- Other than for domestic use, groundwater reserves remain largely underdeveloped and unexploited. To help spur interest, a pilot project in groundwater recharge as opposed to surface water storage (to reduce evaporation losses) should be conducted. The risk of contamination and overdrafting (extracting groundwater beyond the safe yield or equilibrium) needs further investigation.
- It is important that MOWRAM, MAFF and MRD work together at the national and local levels to help local communities improve soil fertility, crop production and livelihoods through promoting water security and agricultural intensification (crop diversification, soil suitability and fertility management, livestock and aquaculture); developing land use planning, crop zoning and cropping calendars; improving cultivation techniques, livestock practices and manure management to reduce methane emissions from irrigated rice fields; and improving nitrogen fertiliser application techniques to reduce nitrous oxide emissions while improving crop yields.

8.3.2 Strengthening human assets

The low capacity of human resources and poor performance in governance suggests the need for cost-effective, low-cost measures to help local communities address current climate variability and extremes and build or improve the availability of and access to key assets. The following recommendations would help strengthen human assets:

- Improved water management requires significant capacity building at national, subnational and community levels on pro-poor sustainable water resources development and management.
- Encourage learning, knowledge acquisition and innovation by providing technical and financial support to local communities and commune councils; broaden participation from stakeholders at all levels in decision-making processes to enhance the resilience of the governance system.
- There are still urgent and constant needs for capacity building and resources for a comprehensive disaster risk management plan, especially early warnings, preparedness, response and recovery, for mainstreaming climate risks into local development plans, and for successful fund mobilisation.

- There is a need to help communities and commune councils explore new ways of raising finance (climate investment funds, private sector and green growth funds), and to include inclusive and sustainable growth priorities in the current national budget allocation and development framework.
- Effective water management and crop planning require reliable data and long range weather forecasts so that managers can know in advance the availability of water in the river system and water structures and so that farmers can adjust crop calendars and crop selection.

8.3.3 Strengthening financial and political assets

The following measures are recommended to strengthen financial management and governance:

- Coalitions are particularly important for collective action, and, where trust and legitimacy are sufficient, can push for orderly change. This emphasises the need for supports to build networks that can help cut across dysfunctional formal relationships and uncoordinated institutional arrangements at national and subnational levels.
- Local management of natural resources remains an essential element for building resilience in social-ecological systems. Community-based natural resource management is crucial to maintaining ecosystem services because state agencies do not have the resources, reach or skills to be as effective as the people and groups with a long-term direct stake in sustainability.
- Informal mutual assistance groups such as savings groups and rice banks help to build a stronger sense of community support and self-reliance and can trigger local innovation.
- Mechanisms, rules and regulations on water use and water fee systems should be properly adopted catchment-wide. For that to happen, training on water management and operation, water regulations and downstream-upstream conflict resolution should be provided to FWUC members.
- Support the shift towards adaptive water governance by:
    - learning and managing for resilience through forward-looking and reflective policy agendas and drawing on lessons learned from experience;
    - being inclusive—supporting skills and means for negotiation and evaluation of management actions in a context with large uncertainties about causes, complex impacts and multiple interests.

- Improve water governance by:
    - ensuring decentralisation reforms are accompanied by mechanisms to maintain effective vertical and horizontal coordination;
    - improving the accountability of authorities at all levels through multiple formal and informal mechanisms;
    - improving procedures to enhance local representation in deliberations over water decisions;
    - increasing the flexibility of rules and procedures and expanding opportunities for social learning; and,
    - acknowledging the important role non-state actors and social networks have in water governance, particularly those that help empower the most vulnerable or help monitor and expose the influence of powerful, narrow and vested interests.

Getting these recommendations off the paper requires a strategy for lobbying decision makers to catalyse changes in attitudes and culture that will eventually translate innovative capacity into effective actions and best practices for adaptation. Financial, human and physical barriers to planned adaptation must be addressed, and opportunities posed by synergies with the sustainable development goals and integrated policies and management practices followed up.

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Glossary of Terms

Jeon Dahee

This glossary gives general definitions for the main climate terms and vocabulary used in this book and in CDRI's publications. Every effort has been made to present accurate and up-to-date definitions. However, this glossary is intended as a resource for non-specialist users, not as an authority. Climate science is a complex and rapidly changing area, and it would be impossible to include every applicable term. Users should refer to standard texts and reference works for more detail.

The definitions in the glossary have been compiled from various sources in good faith. Where these were found to be adequate, they have been used in their entirety, while others have been modified to aid non-specialist users' understanding; they have been referenced to the original source organisation or documentation.

100-year flood: A flood that has a 1 percent chance of being equaled or exceeded in any given year. It is also known as the base flood.[1]

Adaptation: In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.[2]

Adaptation response: Adaptation responses can either reduce vulnerability by insulating against harsh conditions, or increase resilience and/or adaptive capacity by modifying production and consumption to better suit the climate.[3]

Adaptive capacity: The combination of the strengths, attributes and resources available to an individual, community, society or organisation that can be used to prepare for and take actions to reduce adverse impacts, moderate harm or exploit beneficial opportunities.[4]

Adaptive governance: An evolving research framework for analysing the social, institutional, economic and ecological foundations of multilevel governance that are successful in building resilience for the challenges posed by global change, and coupled complex adaptive social-ecological systems.[5]

Aquifer: A layer of permeable rock that stores water. An unconfined aquifer is recharged directly by local rainfall, rivers and lakes, and the rate of recharge is influenced by the permeability of the overlying rocks and soils.[6]

Biodiversity: The variability among living organisms in terrestrial, marine and other ecosystems. Biodiversity includes variability at the genetic, species and ecosystem levels.[7]

Catchment: The area from which water drains into a stream, river or lake.[8]

Climate change: A change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural processes or to human-induced changes in the composition of the atmosphere or in land use.[9]

Climate change impacts: The effects of climate change on natural and human systems. Potential impacts are those that may occur if adaptation measures are not taken. Residual impacts are the impacts of climate change that would occur even with adaptation measures in place.[10]

Climate hazard: Refers to shocks, such as floods (rapid onset), and to stresses, such as droughts or changing rainfall patterns (slow onset).[11]

Climate models: Research tools to study and simulate the climate, including monthly, seasonal and interannual climate predictions.[12] The following models are used in this study:

- **ArcSWAT** (soil and water assessment tool): A physical hydrologic model used for rainfall-runoff modeling, and for predicting the impacts of changes in climate and in land use and land management practices on the hydrology and water quality of watersheds and river basins.[13]
- **CroPWat:** An empirical decision-support system developed by the Land and Water Division of the FAO, well known to farmers for its easy estimation of crop water demands under different irrigation practices.[14]
- **ECHAM** (European Community-Hamburg): An atmospheric global climate model derived from the European Centre for Medium-Range Weather Forecasts spectral prediction model.[15]
- **IQQM** (integrated water quantity and quality simulation model): A river flow simulation model originally developed for the Murray–Darling Basin in Australia.[16]
- **PRECIS** (Providing Regional Climates for Impacts Studies): A regional climate modeling system developed by the UK Met Office Hadley Centre for Climate Science and Services.[17]
- **SEA START** (Southeast Asia SysTem for Analysis, Research and Training): A global network that supports multidisciplinary research on the interactions between humans and the environment.[18]

- **URBS** (unified river basin system): A distributed nonlinear rainfall-runoff routing model which can account for the spatial and temporal variation in rainfall.[19]
- **WEAP** (water evaluation and planning): An integrated modeling framework to evaluate rainfall-runoff for water resources planning that uses time series climate data to estimate water supplies (watershed runoff) and demands (crop evapotranspiration).[20]

Climate risk: Risk is the likelihood of an extreme weather-related event and its potential consequences; risk equals the probability of climate hazard multiplied by a given system's vulnerability.[21]

Climate resilience: When referring to natural systems, the amount of change or disturbance an ecosystem can tolerate and still retain its basic functions. If referring to human systems, resilience is often synonymous with adaptive capacity.[22]

Climate sensitivity: The equilibrium temperature rise that would occur for a doubling of CO_2 concentration above pre-industrial levels.[23]

Climate variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes) of the climate at all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural processes within the climate system (internal variability), or to variations in natural or human-induced change (external variability).[24]

Crop diversification: Cropping system where a number of different crops are planted in the same general area and may be rotated from field to field, year after year.[25]

Crop calendar: A list of the standard crops of a region in the form of a calendar giving the dates for sowing and agricultural operations, as well as various stages of growth, in years of normal weather.[26]

Deforestation: Those practices or processes that result in the conversion of forested lands for non-forest uses. Deforestation contributes to increasing carbon dioxide concentrations for two reasons: 1) the burning or decomposition of the wood releases carbon dioxide; and 2) trees that once removed carbon dioxide from the atmosphere in the process of photosynthesis are no longer present.[27]

Drought: A period of abnormally dry weather long enough to cause a serious hydrological imbalance. Drought is a relative term, therefore any discussion in terms of water deficit must refer to the particular water use. For example, insufficient rain during the growing season affects crop production and ecosystem functions (agricultural drought), and during the runoff and percolation season primarily affects water supplies (hydrological drought). Storage changes in soil moisture and groundwater are also affected by higher evapotranspiration rates in addition to lower rainfall. A period with an abnormal rainfall deficit is defined as a meteorological drought.[28]

Drought management: The concept of drought management is to plan for a year-round water supply except during drought with some calculated recurrence interval, say once in 50 or 100 years.[29]

Early warning system: The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organisations threatened by a hazard to prepare and to act appropriately and quickly enough to reduce the possibility of harm or loss.[30]

Ecosystem: A system of living organisms interacting with each other and their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth.[31]

Environmental sustainability: The rates of renewable resource harvest, pollution creation and non-renewable resource depletion that can be continued indefinitely.[32]

Evapotranspiration: The combined process of evaporation from the Earth's surface and transpiration from vegetation.[33]

Governance: The process of decision-making and the process by which decisions are implemented (or not implemented). Governance can be used in several contexts such as corporate governance, international governance, national governance and local governance.[34]

Groundwater: Water in the ground that is in the zone of saturation, from which wells, springs and groundwater runoff are supplied.[35]

Hydrology: The scientific study of the behaviour of water in the atmosphere, on the Earth's surface and underground.[36]

Irrigation water requirements: The quantity or depth of irrigation water in addition to rainwater required to produce the desired crop yield and quality and to maintain an acceptable salt balance in the root zone.[37]

Integrated water resources management: The prevailing concept for water management, IWRM is based on four principles that were formulated by the International Conference on Water and the Environment in Dublin, 1992: (1) fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment; (2) water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels; (3) women play a central part in the provision, management and safeguarding of water; (4) water has an economic value in all its competing uses and should be recognised as an economic good.[38]

Mainstreaming: The potential impacts of climate change are considered and appropriate adaptation measures are integrated as normal practice within ongoing policy and practice.[39]

Methane emissions: Methane is the primary greenhouse gas emitted from irrigated rice farming systems. Methane emissions from rice fields are determined mainly by water regime and organic inputs, but they are also influenced by soil type, weather, tillage management, residues, fertilisers and rice cultivar.[40]

Overdrafting: Removing more groundwater from an aquifer than is naturally replenished.[41]

Social-ecological systems: Social-ecological systems are nested, multilevel systems that provide essential services to society such as supply of food, fibre, energy and drinking water.[42]

Special Report on Emissions Scenarios (SRES): The storylines and associated population, GDP and emissions scenarios associated with the Special Report on Emissions, and the resulting climate change and sea-level rise scenarios. Four families of socioeconomic scenarios (A1, A2, B1 and B2) represent different world futures in two distinct dimensions: a focus on economic versus environmental concerns, and global versus regional development patterns.[43]

Sustainability: A dynamic process that guarantees the persistence of natural and human systems in an equitable manner.[44]

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.[45]

Vulnerability mapping: The process of establishing where geographically people or systems are particularly vulnerable to a defined hazard.[46]

Vulnerability index: A metric characterising the vulnerability of a system. A climate vulnerability index is typically derived by combining, with or without weighting, several indicators assumed to represent vulnerability.[47]

Water balance: Balance of inflow and outflow of water per unit area or unit volume and unit time taking into account net changes of storage.[48]

Water discharge: In its simplest concept discharge means outflow; therefore, the use of this term is not restricted as to course or location, and it can be applied to describe the flow of water from a pipe or from a drainage basin. If the discharge occurs in some course or channel, it is correct to speak of the discharge of a canal or of a river. It is also correct to speak of the discharge of a canal or stream into a lake, a stream, or an ocean.[49]

Water flow duration curve: A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.[50]

Water governance: The political, social, economic and administrative systems in place that influence water use and management. Essentially, who gets what water, when and how, and who has the right to water and related services, and their benefits.[51]

Water scarcity: Economic water scarcity is described as a situation caused by a lack of investment in water, or a lack of human capacity to satisfy the demand for water. Symptoms of economic water scarcity include scant infrastructure development, either small or large-scale, so that people have trouble getting enough water for agriculture or drinking.[52]

Physical scarcity is said to occur when there is not enough water to meet all demands, including environmental flows. Symptoms of physical water scarcity are severe environmental degradation, declining groundwater, and water allocations that favour some groups over others.[53]

Water security: The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being and socioeconomic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.[54]

Water loss: The difference between the water entering the supply system (through wells, surface intake, and/or wholesale purchase) and water used (sold to customers or used for free).[55]

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Recent CDRI publications on climate change and governance

Sam Sreymom, Ky Channimol, Keum Kyungwoo, Sarom Molideth and Sok Raksa (Forthcoming), *Common Pool Resources and Climate Change Adaptation: The Cases of Community-Based Natural Resource Management in Cambodia.*

Sam Sreymom and Ouch Chhuong (March 2015), *Agricultural Technological Practices and Gaps for Climate Change Adaptation.*

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Kim Sour, Chem Phalla, So Sovannarith, Kim Sean Somatra and Pech Sokhem (August 2014), *Methods and Tools Applied for Climate Change Vulnerability and Adaptation Assessment in Cambodia's Tonle Sap Basin.*

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Chem Phalla, Philip Hirsch and Someth Paradis (September 2011), *Hydrological Analysis in Support of Irrigation Management: A Case Study of Stung Chrey Bak Catchment, Cambodia.*

Ros Bandeth, Ly Tem and Anna Thompson (September 2011), *Catchment Governance and Cooperation Dilemmas: A Case Study from Cambodia.*

Chem Phalla and Someth Paradis (March 2011), *Use of Hydrological Knowledge and Community Participation for Improving Decision-Making on Irrigation Water Allocation.*

“We must turn the greatest collective challenge facing humankind today, climate change, into the greatest opportunity for common progress towards a sustainable future.”

Ban Ki-moon, United Nations Secretary-General

It is evident from global reports that greenhouse gas emissions will continue to grow over the next few decades. It is also clear from the results of the three water balance analyses that hazards and risks associated with more extreme weather patterns in Cambodia’s Tonle Sap Basin will continue to increase. Further, localised changes in ecological systems and the environment being caused by human activities are contributing to the socioeconomic vulnerability of households and communities and will further compound potential sensitivity to climate hazards, socioeconomic conditions and adaptive capacities at all levels.

This multi-aspect site- and context-specific assessment of climate vulnerability explores the impacts of climate variability and change in conjunction with the characteristics of socioeconomic and ecological systems, the effectiveness of related policies and institutions, and different types of coping strategies, among a range of other factors.

The study provides Cambodian and international organisations and stakeholders with information to better identify, design and implement new programs and mobilise potential funds for adaptation responses. It puts forward several sets of recommendations to improve the availability of and access to key physical, natural, social, human, institutional, financial and political assets.

Getting these recommendations off the paper, however, will require a strategy for lobbying decision makers to catalyse changes in attitudes and culture that will eventually translate innovative capacity into effective actions and best practices for adaptation. Financial, human and physical barriers to planned adaptation must be addressed, and opportunities posed by synergies with the Sustainable Development Goals and integrated policies and management practices followed up.

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