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CHEM Phalla and SOMETH Paradis

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Authors:

CHEM Phalla Natural Resource and Environment Programme, Cambodia Development Resource Institute
SOMETH Paradis Department of Rural Engineering, Institute of Technology of Cambodia.

CDRI
56, Street 315, Tuol Kork, Phnom Penh, Cambodia
PO Box 622, Phnom Penh, Cambodia
Tel: (+855-23) 881-384/881-701/881-916/883-603/ 012 867-278
Fax: (+855-23) 880-734
E-mail: cdri@wicam.com.kh
Website: http://www.cdri.org.kh

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Table of Contents

Figures and Tables

Preface

The Cambodia Development Resource Institute (CDRI), in collaboration with the University of Sydney (USYD) and the Royal University of Phnom Penh (RUPP), is currently implementing a Water Resources Management Research Capacity Development Programme (WRMRCDP). It is a five-year research programme that started in July 2006 and is scheduled to complete in June 2011, funded by the Australian Government Agency for International Development (AusAID). The programme focuses on (1) generating knowledge related to irrigation management, (2) building research capacity related to the management of water, and (3) disseminating knowledge gained from the research in order to improve water management in Cambodia.

The WRMRCDP has allowed Cambodian researchers to explore catchment management through case study data collection, and analyse existing policy on the water sub-sector through literature review. The benefits to Cambodia from this research programme are fourfold. First, the capacity for water resource research is being improved through academic study and participatory learning and action research with the support of academic researchers from the University of Sydney. Second, the research theme addresses improving water management. Third, participatory learning and action research provides deeper insight and broader understanding of water management. And fourth, wide dissemination of the research findings provides good information to the Ministry of Water Resources and Meteorology (MOWRAM) and its provincial departments, and farmer water user communities (FWUCs).

The research is being carried out in three sub-catchments of the Tonle Sap Lake in three provinces: Kompong Chhnang, Pursat and Kompong Thom. The main stakeholders are officials and staff from MOWRAM, the Ministry of Agriculture, Forestry and Fisheries (MAFF) and its provincial departments, the Technical Working Group on Agriculture and Water (TWGAW)[1], NGOs, district officers, commune councillors, FWUC members and farmers.

The research was framed through a review of existing literature and the conduct of four case studies for data collection, i.e. a social assessment of irrigation. The literature review explored international and national experiences on governance and technical issues related to water resources and the social assessment was to observe current provincial and community irrigation management practice. The literature review has been published as a working paper titled "*Framing Research on Water Resources Management in Cambodia: A Literature Review*" (CDRI 2008), and the social assessment of irrigation as "*Empirical Evidence of Irrigation Management in the Tonle Sap Basin: Issues and Challenges*" (CDRI 2010). These two studies form the research framework for the WRMRCDP, which consists of governance, economic and physical research components. This paper presents only the hydrological analysis and some aspects of catchment management of the physical research component.

1 The TWGAW was established by the government to facilitate sector coordination and develop a strategy for the agriculture and water so as to meet national agricultural development goals.

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The authors express their deep gratitude to Dr Sin Sovith, senior programme manager, and Mr John Dore, regional water and infrastructure advisor of the Australian Agency for International Development, who regularly reviewed the study's progress and provided feedback to the researchers. This support enabled CDRI and its partners to implement the WRMRCDP successfully and publish this paper.

Thanks are also due to officials from the Ministry of Water Resources and Meteorology (MOWRAM) and Ministry of Agriculture, Forestry and Fisheries (MAFF), who supported and participated in the WRMRCDP. Special thanks go to Mr Chann Sinath, deputy secretary general of MOWRAM and co-chair of WRMRCDP, and Mr Mak Soeun, director of agricultural extension, MAFF, for their support in the analysis of agriculture-water management issues and their policy recommendations indicated in this paper.

The authors likewise thank the staff of the provincial departments of MOWRAM in Kompong Chhnang, Pursat and Kompong Thom for their active involvement in the participatory research, training and dissemination. They contributed in data collection, coordination and provision of local knowledge. Their support enabled WRMRCDP to conduct commune and provincial workshops.

Finally, the authors extend deep thanks to the district governors of Tuek Phos and Rolea Bíer districts, the commune councillors of Kork Banteay, Chrey Bak, Tang Krasang, Chaong Maong and Tuol Khpos, farmer water user community members and farmers in Pok Paen, Svay Chek, Tang Krasang and Trapeang Trabek irrigation schemes who actively participated in the research. The hydrological observers - Mr Khem March, Mr Chan Sim, Mr Chak Somaly and Mr Chey Saluon - also deserve thanks for their collaboration and participation in the hydrological data collection.

Acronyms and Abbreviations

AFSC-C	American Friends Service Committee – Cambodia
AusAID	Australian Aid for International Development
CDRI	Cambodia Development Resource Institute
CODE	Coefficient of Determination
CTA	Technical Centre for Agricultural and Rural Development
FLOW	The Essentials of Environmental Flows, Water and Nature Initiatives of IUCN
FWUC	Farmer Water User Community
GWP	Global Water Partnership
ICM	Integrated Catchment Management
IIED	International Institute for Environment and Development
ISF	Irrigation Service Fee
ITC	Institute of Technology of Cambodia
IUCN	International Union for the Conservation of Nature
IWRM	Integrated Water Resources Management
KEIRIN	Engineering and Consulting Firms Association, Japan KRI International Corp
MAFF	Ministry of Agriculture, Forestry and Fisheries
MOWRAM	Ministry of Water Resources and Meteorology
MRC	Mekong River Commission
MRD	Ministry of Rural Development
NGO	Non Governmental Organisation
NIS	National Institute of Statistics
NISDP	Northwest Irrigation Sector Development Project
PDOWRAM	Provincial Department of Water Resources and Meteorology
PIMD	Participatory Irrigation Management and Development
PICM	Participatory and Integrated Catchment Management
PLA	Participatory Learning and Action Research
PRASAC	Programme de Réhabilitation et d'Appui au Secteur Agricole du Cambodge
RGC	Royal Government of Cambodia
RMSE	Root Mean Square Error
RUPP	Royal University of Phnom Penh
SAW	Strategic Plan for Agriculture and Water
TWGAW	Technical Working Group on Agriculture and Water
UNDP	United Nations Development Programme
USYD	University of Sydney
UTM	Universal Transverse Mercerator
WRMRCDP	Water Resources Management Research Capacity Development Programme

Executive Summary

This working paper presents the results of the physical component research of the Water Resources Management Research Capacity Development Programme. This research was conducted in Stung Chrey Bak catchment in Kompong Chhnang province, aimed at generating knowledgeable interaction between water use, policy, physical systems and institutional frameworks around catchment management. It used a participatory action research method for interactive learning and data collection. The stakeholders are the Ministry of Water Resources and Meteorology (MOWRAM) and the Ministry of Agriculture, Forestry and Fisheries (MAFF) and their provincial departments, district officials, commune councillors, farmer water user communities (FWUCs) and farmers. Initial findings include stream discharge, rice crop water requirements and issues related to water catchment management.

Irrigated areas have expanded due to population growth. A growing population requires more food. In order to meet food demand, people exploit more natural resources and intensify agricultural production. Many farmers who grow dry season rice lack irrigated water. The lack of irrigated water is not just because of a lack of water in the catchment, but also due to the lack of irrigation infrastructure and a proper water allocation mechanism. Consequently, the allocation of irrigation water between different irrigation schemes and also between users within the same scheme is neither timely nor equitable. This creates intense competition over water.

Fragmented irrigation management arises from the lack of good coordination between FWUCs and water user sectors. The development of the irrigation sector has been single-sector oriented and ad hoc. Many irrigation schemes were constructed during the 1980s and 1990s with assistance from international organisations. A main purpose of irrigation infrastructure development at that time was to increase food security and reduce poverty. However, these developments failed to establish a catchment management mechanism. FWUCs and commune councillors focused only on their own local schemes. The FWUCs planned cropping individually without consulting each other. As a result, irrigation water allocation was not properly planned. Some dry season crops were lost due to lack of water. There was intense competition and conflict over water. District authorities rarely communicated with FWUCs unless they were asked for help with conflict over irrigation water. The Provincial Department of Water Resources and Meteorology (PDOWRAM) helped resolve conflict by looking at water availability in each scheme and trying to adjust the flow. But with limited infrastructure, financial and technical support, PDOWRAM could not assist the FWUCs in an effective and timely manner. As a result, many farmers had limited access to irrigation and the potential benefits of irrigation were lost.

Lack of hydrological knowledge creates difficulties in water allocation, particularly when dealing with different irrigation schemes. An understanding of spatial and temporal distribution of water flow can improve catchment resources planning. More specifically, an understanding of the catchment processes that link physical systems (e.g. water movement, communities and environment) from upstream to downstream could help identify possible impacts of upstream development on downstream water users.

Stream discharge analysis found that annual run-off in the catchment was about 284 million cubic metres. The peak flow usually occurs in September–November, accounting for about 89 percent of the total annual run-off. The lowest flow, about 4 million cubic metres, was observed in March.

The low flow severely impacts on dry season cultivation in downstream areas, especially in Tang Krasang and Trapeang Trabaek. This raises the question of water allocation and sharing during the peak demand in February and March when the stream discharge is at its lowest.

Previous studies on the crop water requirements of an early rice variety (around 105 days) show that consumption ranges from 560 mm for silt paddy field to 986 mm for sandy loam paddy field in the floodplain of the Tonle Sap Lake. Based on water availability in the Stung Chrey Bak catchment, it is concluded that the total water withdrawal in the wet season is about 191 million cubic metres, which could potentially irrigate 19,000 to 34,000 hectares of 105-day rice. At Trapeang Trabaek, with its clay soil paddy fields in the floodplain of the Tonle Sap River, the on-site-water-requirement measurement shows that consumption is about 500 mm for 90-day rice. This suggests that the current cultivated area of 800 hectares needs 4 million cubic metres of water.

Along with water shortage, the lack of infrastructure also limits irrigation. Inadequate infrastructure has created problems in water allocation. Farmers irrigate their rice fields from plot to plot. This wastes a lot of water and to some extent causes water shortages downstream. In addition, integrated irrigation planning and management are lacking. The low management capacity of FWUCs requires more assistance from PDOWRAM. However, because PDOWRAM also lack financial and technical capacity, they cannot assure technical and legal assistance to FWUCs. Farmers, not having enough water to irrigate their fields, stopped paying the irrigation service fee. The FWUCs, not having enough financial and technical support, dropped their roles, and newly established FWUCs have become dysfunctional. This is why many roles of the FWUC have been taken up by village leaders or commune councillors.

Many areas are shifting from rain-fed to irrigated farming. This has increased the demand for water. A participatory integrated catchment management (PICM) approach is recommended to enhance management for sustainable irrigation. Such an approach requires multiple skills and on-the-job training to improve the technical and operational skills of PDOWRAM staff and FWUC members. Hydrological data also need to be collected and recorded. Based on the findings of the research, the following are the recommendations to improve the management of water resources:

- Collection of stream level, rainfall and meteorological data should be continued.
- Rating curves of the main stream and reservoir are important in irrigation planning. This knowledge should be transferred to FWUCs and PDOWRAM.
- Irrigation infrastructure should be rehabilitated.
- A rehabilitation programme should be planned using PICM.
- MOWRAM, PDOWRAM and related provincial departments, CDRI, donors, provincial governors and local authorities should be involved.
- A catchment management working committee comprising relevant provincial technical departments should be established.
- All FWUCs involved in the catchment should have a seat on the working committee.
- Local authorities' roles in irrigation management should be recognised.
- Financial and technical support should be provided to improve the performance of FWUCs and PDOWRAM.

1

Introduction

Water has always been at the heart of Cambodia's economy and culture. Cambodia's water resource is strongly dominated by the hydrological and climatic conditions of the Mekong River Basin whose catchment covers over 86 percent of the country's territory. The Mekong River system is shared by Cambodia, Vietnam, Laos, Thailand, Myanmar and China.

Theoretically, water is abundant in Cambodia; its abundance depends upon the season, geography and climate. Much of the runoff occurs in flood events (flow in the flood season accounts for 85-90 percent of the total annual water volume) or is inaccessible to human beings because of its remote location and part of the runoff needs to be maintained for other in-stream uses and other social and ecological purposes (WRI 2000).

Many communities experience water shortage in the dry season and annual flooding in the wet season. The greater frequency of abnormal flood and drought in recent years is cause of increasing concern. How rising temperatures and greater variability of rainfall will affect the Tonle Sap basin is yet to be ascertained. According to global climate modelling, downscaled to basin level by the Mekong River Commission (MRC) and its partners, the likely change in rainfall patterns and extreme temperatures could increase the likelihood of drought and flood and affect agriculture and farmers in poor areas (MRC 2010). The principal costs of drought relate to the impact on agriculture such as reduced yields or total loss of crops, especially rice, together with reduced livestock and fishery yields as well as increased susceptibility to disease and additional hardship.

Water shortage is caused by increased demand, environmental deterioration and the lack of proper management. When communities face water problems such as too much or too little water, technical, institutional and social interventions are required. Science should be able to determine the status of water resources and science-based policy should guide water investment decision; management institutions should help farmers and water users use water wisely, sustainably and equitably.

Cambodia has adopted integrated water resources management (IWRM) (Law on Water Resources Management 2007). IWRM requires coordinated management and development of water, land and related resources (fisheries) in order to maximise economic and social welfare without compromising the sustainability of vital ecosystems (Global Water Partnership 2000, cited in Rogers & Hall 2003).

In our study areas in the Tonle Sap Basin, hydrological regime, ecological characteristics and livelihood activities of the local people are strongly interrelated. An important aspect of water management is catchment hydrology and processes. Water movement, including surface and groundwater flows, infiltration and human economic activities, links many communities and ecosystems in a complicated cause and effect upstream-downstream relationship (Knox *et al.* 2001). Water, humans and the environment in upstream and downstream locations are connected through these hydrological processes. That is why catchment hydrology considers the landscape of the catchment as the primary unit for managing water. Even insignificant change in hydrological processes impacts on rivers, their vital ecosystem components and groundwater.

Many human activities can harm or disconnect the hydrological and geo-morphological processes. Dam-building is one of main economic activities. Dams store much water in upstream locations. They divert or temporarily impound large volumes of water that would otherwise flow downstream naturally. They disconnect hydrological processes by changing the quantity and quality of water and often result in too little or too much water, creating a barrier to fish migration or sediment movement. Irrigated agriculture also consumes large amounts of fresh water and often creates water scarcity, and the associated application of agro-chemicals (fertilisers, herbicides, pesticides) pollutes the lower catchment. When water is scarce, the competition for it is always intense (Wester *et al.* 2005); therefore, the legitimacy and fairness of water allocation have become a major concern (Grabow & McCornick 2007). In an effort to satisfy growing demand for food, fibre and energy, pristine ecosystems have been converted to alternative uses. The manner in which communities manage their land and water resources has a profound effect on other communities and the functionality of these systems in the provision of goods and services.

IWRM or integrated catchment management (ICM)[2] can help address management issues caused by single-sector-oriented water management. IWRM and ICM consider the full array of physical and socio-economic variables, and aim to conserve water for environmental and human needs (Hooper 2003). Consequently, the catchment becomes the overall management unit for land and water resource managers as well as policy makers. The concept of the hydrological cycle is essential in IWRM/ICM since it views the catchment, where rainwater is captured, stored, processed and distributed, as the main natural unit for managing inland water.

1.1 Research Problem

Surface and groundwater have been used for irrigation and domestic purposes in Cambodia since ancient times. Irrigation infrastructure such as reservoirs, dykes, inlets, outlets, drainage canals, spillways, weirs and regulators has been widely utilised in surface water management for irrigation, whereas wells are normally used for collecting groundwater for domestic use and household gardening. The West Barai reservoir continues to serve as a multi-functional hydraulic system. The reservoir receives water from the Stung Siem Reap through Prasat Keo intake canal and diversion weir. Water from the reservoir is used for irrigation as well as other domestic, religious and recreational purposes. Agricultural production has intensified, largely driven by population growth. Irrigation contributes to this and noticeably improves food security.

Catchment hydrology is one critical aspect of water resources management. Understanding the interconnections between water movement in the catchment helps improve water management. The movement of water links communities and other upstream and downstream water-using sectors in a complicated relationship linked to the quantity and quality of water, and impacts on key ecosystem components, and environments. Even some insignificant changes in hydrological processes, for example changes in the upstream areas due to deforestation, water impoundment and diversion for irrigation, potentially have large scale negative single or cumulative impacts on downstream water users. A lack of understanding about these processes and a lack of recognition of the interconnections between reservoirs risk unsustainable irrigation development (CDRI 2008).

2 ICM is a multi-stakeholder approach for managing land, water and other related natural resources to bring about sustainable economic, ecological and social benefits within the hydrological boundary.

Hydrological change in Cambodia is caused by land cover change and dam-building, and possibly climate change. A change in catchment hydrology impacts on water users by causing unusual flooding or water shortage. A physical shortage means there is not enough water to meet demand. In a situation of physical scarcity, properly constructed, operated and managed infrastructure is important for harvesting and storing excess water from the wet season for use in the dry season. Cambodia also faces economic scarcity of water due to lack of investment in the water sector. Scarcity is also caused by inadequate institutional and organisational capacity and knowledge for informed decision making on sustainable water investment and sustainable agriculture, i.e. institutional scarcity. Cambodia's irrigation sector has been facing economic, physical and institutional scarcity in the dry season.

Water scarcity affects income generation and causes environmental degradation and social conflicts, slowing down poverty reduction and affecting social harmony and unity. Economic water scarcity is fairly severe because of the lack of capacity to capture water for wet season supplementary irrigation and dry season irrigation. At the same time, physical water scarcity is a growing cause for concern because of the climatic conditions in the dry season and increased competition for water. To overcome seasonal water shortages, storage facilities have been built as part of some irrigation schemes. However, the existence of poorly conceived and poorly managed water infrastructures also contributes to abnormal flood and water scarcity.

Stung Chrey Bak catchment, in Kompong Chhnang province, is the case study site for WRMRCDP's physical research component. Water in the catchment is used intensively for wet and dry season paddy rice production, home gardening and domestic purposes, including livestock. There are four main irrigation systems in the catchment. From upstream, they are Pok Paen, Svay Chek, Tang Krasang and Trapeang Trabek. Small dams and stream weirs have been built to retain and divert water.

The planning and management of these irrigation schemes is fragmented. Water shortage in the dry season is a major problem. Most irrigation schemes were built without integrated and participatory planning, which led to lack of sense of ownership and unclear responsibilities. The design and construction of the schemes were often based on limited hydrological and other relevant information (CDRI 2010).

Coordination between schemes rarely happens and if it does, is rarely effective. As such, a conflict has emerged between upstream and downstream users over the use of water for irrigation. If management is fragmented, the lack of hydrological information and poor coordination persists, the water use landscape at the site is further complicated and can become dangerously explosive. Enabling conditions conducive to the introduction of alternative livelihood and income generation options are yet to be assessed and created.

In summary, participatory integrated management is difficult to apply and highly fragmented at all levels. In addition, a number of factors (e.g. financial and institutional scarcity, access to knowledge) have limited the sustainability and reliability of community-based integrated management. Invariably, the unsustainable utilisation of resources is driven by the limited capacity of communities to implement sustainable practices due to immediate needs and low resilience, the lack of quick and tangible outcomes and the limited resources at their disposal.

This problem analysis does not take into account the future impact of climate change and other hydrological and environment changes due to trans-boundary impacts. It is expected that the challenge will become more intense because the demand for water is going to increase further due to rapid population growth. In the meantime, water resources availability is further constrained due to climate change and environmental degradation. All these problems may potentially lead to social unrest and undermine poverty reduction efforts.

1.2 Research Questions

Two research questions have been used in the physical component research. These are:

1. What are the roles of hydrological knowledge in improving equitable access to water and sustainable use of water resources for agricultural and food production?
2. What are the most pressing issues in current water allocation practice in relation to catchment management arrangements?

1.3 Overall Research Goals

This research intends to impact on the optimisation of upstream-downstream water use for increasing agricultural production, ensuring equitable benefit, reducing conflict related to water use and building capacity in integrated catchment management in Cambodia. This is to be achieved through the implementation of a participatory learning and action research (PLA) to (i) generate knowledge on catchment hydrology and processes, (ii) analyse key problems related to coordination and water allocation, and (iii) identify a practical solution for improving water management in the context of irrigation and livelihood development.

Textbox 1: Participatory Learning and Action Research

Participatory Learning and Action is an umbrella term for a wide range of similar approaches and methodologies, including participatory rural appraisal, rapid rural appraisal, participatory learning methods, participatory action research, farming systems research, méthod active de recherche et de planification participative, and many others. The theme common to all these approaches is the full participation of people in the processes of learning about their needs and opportunities, and in the action required to address them (IIED & CTA 2006).

The methods used range from observation, to interviewing and group work. The common theme is the promotion of interactive learning, shared knowledge, and flexible, yet structured analysis.

Common principles of PLA:

- A defined methodology and systematic learning process by the stakeholders through a system of joint analysis and interaction.
- Multiple perspectives reflecting the various interpretations of reality and solutions for problems by the different stakeholders (seeking diversity and differences).
- Shared learning process through group analysis and interaction.
- Context specific methods and approaches designed or adapted to the local situation, preferably by the actors involved (ownership).
- Facilitating experts and stakeholders: the role of outsiders is to act as catalysts (facilitators) for local people to decide what to do with the information and analysis they generate. Outsiders may also choose to further analyse the findings generated by PLA to influence policy-making..
- Leading to change: the process of joint analysis and dialogue helps to define changes which would bring about improvement and seeks to motivate people to take action to make these changes.

1.4 Research Objectives

The main objective of the research is to interactively generate knowledge regarding water use, physical water resources, institutions and policy around catchment management in irrigation and livelihood development. The investigation focuses on two aspects, namely catchment hydrology and water resources management policy.

The first specific objective is to generate knowledge on the catchment's hydrology. To achieve this, the research team set up a data collection network and analysed stream flow to understand the spatial and temporal distribution of water in the catchment.

The second specific objective is to improve the use of water for agriculture in an equitable manner and encourage sustainable management of the catchment's water and related resources. Participatory learning and action (PLA) research identified challenges and solutions for improving management of the catchment.

1.5 The Impact Pathways

To achieve the expected impacts, the PLA focused on informed water allocation analyses, identifying key challenges and opportunities for improving water management, and capacity building. The result of these analyses is anticipated to contribute to the harmonisation of water usage between upstream and downstream communities, reduction of conflict and development of capacity in the use and management of water resources.

It is expected that many challenges will need to be overcome to achieve the development objectives of this programme. Practices cannot be changed unless the actors are willing to change. Only actors who have a stake in decision-making about water resources management can make effective changes. In order to improve water management practice, the research strategy aimed to introduce policymakers and practitioners to new practical approaches. The impact pathways model shown in Table 1 was designed to achieve the expected programme outcome.

Table 1: The Impact Pathways Model of the Physical Research Component

(4) Actors	(3) Change in practice	(2) Change in knowledge, skills, attitude	(1) Strategies
MOWRAM, MAFF, TWGAW, CDRI, USYD , RUPP, ITC, provincial authorities[a/], PDOWRAM, FWUCs, farmers	- Decision-making on water allocation improved - Irrigation water allocation and crop planning improved - Delivery of irrigation services improved	- Hydrological knowledge improved - Catchment water management improved - Irrigation management improved - Sharing of water improved	- Participatory learning and action research on: • Hydrological knowledge • Water allocation • New approach to water management • Capacity building

a/ Provincial authorities refer to sub-national administration, including the municipality cabinet, district authorities and commune councillors

2

Literature Review

2.1 Water Resources Management in Cambodia

Water and water related resources have contributed significantly to Cambodia's socio-economic development. Water is more than just a resource for economic development and livelihood subsistence. It has been at the heart of Cambodian religion, economy, politics and culture over time. Irrigation infrastructures such as reservoirs, irrigation and drainage canals and hydraulic facilities have been widely used since ancient times. For example, the four reservoirs in the Angkor area – Indratataka (Barai of Loley), East Barai, West Barai and Jayatataka (North Barai) (Evans 2002 cited in Kummu 2003) – were designed for aesthetic, religious and domestic needs as well as for transport, irrigation, drainage, defence and fisheries (Kummu 2003).

Many irrigation systems were built between 1975 and 1978 because the Khmer Rouge perceived water as a means to its political ambition. The regime's main slogan was: "If we have water, we can have rice; with rice, we can have everything" (Sina Than 1982, cited in Shrestha 1994: 5). However, some of the irrigation structures built during those years were technically inappropriate. Poor quality construction and a decade of social unrest left Cambodia with low financial and technical capacity to properly manage its existing water resources management infrastructure.

Water for irrigation, fisheries and domestic and industrial use as remained important for economic development since the end of the Khmer Rouge era. Most of the old irrigation structures were gradually rehabilitated from 1979 until the 1990s (MOWRAM 2009). Majority of the financial and technical support for rehabilitation came in emergency mode from international aid programmes to meet food needs. The rehabilitation works were ad hoc and lacked an integrated policy framework.

Water management has gained further momentum since the establishment of the Ministry of Water Resources and Meteorology (MOWRAM) in 1999. Since then, national managerial capacity has grown through technical assistance and experience and additional financial and technical support has been mobilised. At institutional, i.e. policy level, Cambodia has adopted:

- Law on Water Resources Management (2007)
- Strategic Plan on Agriculture and Water (SAW) for 2006-2010 (2007) and 2009-13 (2010)
- National Policy on Water Resources Management (2004)
- Participatory Irrigation Management and Development (PIMD)
- Prakas (proclamation) No. 306 for establishing community-based water management
- Circular No. 1 on the implementation of sustainable irrigation policy (2000).

Other pending policies and regulations include (i) sub-decrees on the procedure for establishing a farmer water-user community, (ii) river basin management, and (iii) water allocation and water use permits.

The Law on Water Resources Management, adopted by the National Assembly on 22 May 2007 and the Senate on 11 June 2007, is to foster effective and sustainable management of water resources in Cambodia for the socio-economic development and the welfare of the people. This law focuses on three key aspects (Article 1):

- rights and obligations of water users;
- overarching principle for water resources management; and
- participation of FWUCs in the sustainable development of water resources.

On the *rights and obligations of water-users*, the law stipulates that every person has the right to use water resources in a quantity not exceeding his or her basic needs (Article 11). The diversion, extraction and use of water resources for agricultural or industrial purposes in excess of basic needs is subject to a licence or permit (Article 12). It also stipulates that the owner of upstream land is entitled to collect and use rainwater and surface water flowing over his or her property for the purpose of satisfying his or her basic needs and in such a manner that it does not affect the legitimate interests of downstream users, reflecting the principle of equitable utilisation and distribution of benefits (Article 27). The owners of both upstream and downstream land have no right to obstruct the natural flow of water by building a road, dyke or a water storage structure without appropriate authorisation. The owner of agricultural land shall allow water to flow naturally over his or her land to meet adjoining land owners' irrigation and other needs (Article 28).

On the *overarching principles for water resources management*, water and water resources shall be managed and developed based on an IWRM approach (Article 4). This approach should take into account:

- all aspects of water resources;
- linkages between water resources and other components of the natural environment; and
- water requirements for humans, the environment and other sectors.

Cambodia's water law, while empowering MOWRAM to manage, lead and supervise the implementation of the present law, requires that IWRM is to be carried out jointly and in cooperation with all relevant institutions (Article 4: paragraph 3; Article 5). The law also allows the government to set up a joint commission or committee for addressing and coordinating works and activities among the ministries concerned (Article 5).

The *participation of FWUCs* in the development of water resources for ensuring effective, efficient and sustainable management and operation of the irrigation system is stipulated in Article 19, Chapter IV. Based on credible need assessments, MOWRAM may initiate the creation of a FWUC which must be registered at the Provincial (or municipal) Department of Water Resources and Meteorology (PDOWRAM).

As more farmers look to irrigation to meet their food needs, the demand for water during the dry season and technical help to deal with pests is growing. The government gives high priority to water for development for poverty reduction, and therefore water management has to be more effective and carefully analysed, especially as Cambodia moves from rain-fed to irrigated agriculture.

2.2 Multi-Functionality of Irrigation Systems and Paddy Fields in Agriculture and Water Management

Current water use in Cambodia is estimated at about 750 million cubic metres a year, 95 percent of it in agriculture (MOWRAM 2009). Although other sectors take only 5 percent of the total water, fisheries, navigation, energy, domestic water supply and sanitation are equally crucial for people.

In addition to agriculture, irrigation systems have external functions related to the hydrological cycle, biodiversity, culture and recreation. In Komping Puoy Reservoir in Battambang province, Trapeang Thmar Reservoir in Banteay Meachey province and Mlich Reservoir in Kampot province, for example, irrigation systems have served as flood control mechanisms, recreational facilities and conservation areas in addition to providing water for irrigation. Better understanding of the multiple roles of agricultural water management systems reveals important criteria for efficiency, productivity, sectoral allocation and institutional set-up at catchment or river basin and irrigation system levels, and cost recovery and financing of water resources management (Chen & Facon 2005).

Rice is the major irrigated crop in Cambodia; about 43 percent of the paddy rice fields [3] were irrigated in 2008 (MAFF 2008, cited in MOWRAM 2009). Chen and Facon (2005) divide the functions of agricultural irrigation systems into three broad categories: livelihood and economic, hydrological cycle and ecosystem, and social and cultural.

2.2.1 Livelihood and Economic Functions

The livelihood and economic functions of an irrigation system are domestic water supply, aquaculture, rural enterprise, sanitation and, in some cases, power generation. Cambodia's rural population has limited access to a clean water supply. Farmhouse water supply is often based on groundwater or rainwater harvesting because there is no piped water system (KEIRIN 2009). Irrigation systems with storage capacity can be a useful water source for the rural population.

Irrigated paddy fields in the Mekong delta are important in aquacultural ecosystems such as rice-fish cultivation (MRC 2010). The fish yield is estimated at between 50 to 100 kg per ha per year (MRC 2010). Irrigation systems can also be a very important source of water for other rural economic activities, such as small enterprises and restaurants. In the absence of a domestic piped water system, an irrigation system can provide water for sanitation in rural areas. Finally, large and medium irrigation systems could help generate power, either at the reservoir or in the main channels (Chen & Facon 2005).

2.2.2 Hydrological Cycle and Ecosystem Functions

The hydrological cycle and ecosystem functions are: flood control, groundwater recharging, water quality improvement, biological conservation and climate adjustment.

Irrigation systems hold run-off during the peak rainy season. It is estimated that about 20 percent of the flood water in the lower Mekong in 1999 and 2000 was temporarily retained in paddy fields and was available for use downstream after the flood (Masumoto *et al.* 2004, cited in Chen & Facon 2005).

3 In total, 2,615,741 hectares were under paddy rice cultivation in 2008, about 1,120,246 hectares of which were irrigated. Of the irrigated areas, 347,058 hectares were under dry season irrigation and 773,188 hectares under wet season supplementary irrigation (MOWRAM 2009)

Surface water recharges the groundwater, depending on soil type, water and soil temperature, topography and water table level (Liu *et al.* 2004, cited in Chen & Facon 2005). Studies on groundwater recharge in Cambodia are very limited. However, a study in Japan found that 85 percent of its groundwater recharge was from paddy fields (Ichikawa 2002, cited in Chen & Facon 2005), compared to 21–23 percent in Taiwan (Liu *et al.* 2001, cited in Chen & Facon 2005).

The quality of water held in a paddy field may be improved as a result of the soil's capacity to hold contaminants such as heavy metals and filter toxic elements from the water (unless farmers make extensive use of agro-chemicals e.g. fertiliser, herbicide, insecticide). A wetland paddy field pond has the capacity to remove nitrogen and phosphorus (Chen & Facon 2005).

Rice fields provide rich aquatic habitats that support and conserve biological diversity. These habitats are important for maintaining sustainable ecosystems, such as Trapeang Thma irrigation system in Banteay Meanchey which provides an important habitat for cranes.

Lastly, the evapotranspiration of a rice field is significant. It reduces ambient temperature around the paddy field during the dry season (Yokohari *et al.* 1998, cited in Chen & Facon 2005) though it may increase the temperature in the wet season (Wu & Lee 2004, cited in Chen & Facon 2005).

2.2.3 Social and Cultural Functions

Irrigation systems have three social and cultural functions: community empowerment, cultural heritage preservation and ecotourism.

Traditional paddy cultivation was managed by local farmers. In the current context of decentralisation, many farmer groups or organisations associated with rural water management, such as the FWUCs, have been established. Case studies in Bali, Indonesia, and the Philippines report that farmers also share water in religious or social activities (Satawan 2002, cited in Chen & Facon 2005). Various attempts to involve local farmers or water user groups more in the management of large-scale irrigation schemes in Laos and Thailand have had mixed results, mainly due to lack of proper empowerment and ownership, clear roles, financial, technical and human resources (Williams & Weal 2006).

The heritage of water management architecture, such as reservoirs and paddy field bunds, as well the spiritual tradition of revering and conserving nature has shaped traditional rural landscapes. The West Barai irrigation system is an example of the spiritual and cultural values of the water management system. The traditional landscape of irrigated paddy fields presents a living picture of cultural and aesthetic values that is attractive to eco-tourism.

2.3 The Challenge of Irrigation Management

Although the various functions of irrigation systems have been identified, the formal integration of these multiple functions into policy remains limited. Most financial support aims at improving irrigation systems, but the social costs and benefits of irrigation management and its links to rural livelihood are yet to be fully understood.

Another challenge affecting irrigation system management is weak institutional capacity in water resources management. The sectoral approach is dominant in most Southeast Asian countries. In Cambodia, three ministries have been mandated responsibility for irrigation development: MAFF, MOWRAM, and the Ministry of Rural Development (MRD). The PDOWRAM's and FWUCs' poor operational capacity also constrains water resources management, limiting recognition and integrated assessment and evaluation of the multiple functions of the irrigation system. Additionally, due to limited financial and human resources, most irrigation systems in Cambodia lack a network for data collection and information dissemination. Lack of data makes assessing and evaluating the multiple functions of irrigation systems very difficult.

International experience shows that improper use of water has different impacts on water resources, as illustrated in Table 2.

Table 2: Impact of Water Use Sectors on Water Resources

	Positive impacts	Negative impacts
Environment	Purification Storage Hydrological cycle	
Agriculture	Return flows Increased infiltration Decreased erosion Groundwater recharge Nutrient recycling Fisheries	Depletion Pollution Sanitation Water logging Erosion
Water supply and sanitation	Nutrient recycling	High level of water security required Surface and groundwater pollution

Source: Cap-Net, GWP & UNDP 2005 cited in Chen & Facon 2005

2.4 Participatory and Integrated Catchment Management

Given that many communities experience water shortage, and that this problem is expected to become more critical in the near future, many countries, including Australia, have adopted participatory integrated catchment management (PICM) to address sustainable water use. Since many integrated catchment management initiatives have had different outcomes, German *et al.* (2006) undertook a critical review to assess the key principles, benefits and methods that could be adapted for improving sustainable water management.

Various interests focus on different objectives of PICM, depending on their specialism. Agronomists see it as an approach for scaling out technologies, especially for soil and water conservation. The water resources sector sees PICM as enhancing environmental services and public goods for communities in the upper catchment. Conservationists view PICM as a framework for enhancing trans-boundary natural resources management. Social scientists see PICM as a framework for collective action and equity in natural resources access and governance that cannot be resolved at farm level (German *et al.* 2006).

PICM has two characteristics. First, it must be participatory at problem definition, planning and implementation. Second, it must be integrated and reflect technical, social and institutional dimensions (German *et al.* 2006). The objectives include conservation, food security and or income generation (Shah 1998, cited in German *et al.* 2006). PICM is derived from participatory action research, having developed through reflection and learning from practical experience. Key features of participation and integration are (German *et al.* 2006):

Participatory processes

1. Problem definition: defining research objective and method - what questions should be asked in the interview checklist.
2. Participatory planning: involving stakeholders to ensure equitable outcomes from both technical and social standpoints. Three factors should be considered to ensure genuine participation:
   a. The level at which planning is carried out
   b. Whether to plan multiple issues simultaneously or plan around specific issues
   c. How to address social trade-offs in decision-making.
3. Participatory implementation helps foster greater access to programme benefits as many participants are actively engaged the programme. It is important that the participatory evaluation and monitoring framework reflects capacity building and training needs.

Integrated processes

1. Problem definition through exploring interdisciplinary or multi-stakeholders' problems, including biophysical, social, policy and market dimensions.
2. Integrated planning through both component integration and discipline or sectoral integration. For example, the water and soil conservation component may include water quality improvement, flood and drought management.
3. Integrated implementation: First, scientists work independently to ensure the programme goal is achieved. Second, the various components or disciplines are integrated. Finally, lessons are drawn for integrated programme implementation.

2.5 Proposed Steps of National Environmental Flow Programme

The proposed steps for improving integrated catchment management, based on the IWRM Training Manual (International Union for the Conservation of Nature 2003, cited in Chen & Facon 2005) are:

Establish data collection	Hydrological and hydraulic conditions (river flows, water level and river cross-section and ecology, including species)
Identify expertise	Expertise within universities, consultants, government agencies and NGOs in subject areas such as hydrology, hydraulics, water chemistry, botany, aquatic invertebrate and vertebrate zoology, geomorphology and engineering
Create a data centre and library	To be available to all and its existence publicised
Conduct a training course	Build local institutional structure to undertake assessment
Develop and start implementing a research programme	Appropriate methods for local research. The methods need to be tested under specific conditions before the actual assessment. It is important that the methods are compatible to attain consistent results
Conduct a pilot study	Use local expertise and methods and available data to compare outcomes and test appropriateness.

2.6 The Value of Hydrological Knowledge in Water Management Policy

The management of water involves handling hydrological change caused by flood and drought. Hydrological change affects society, the economy and the environment. Knowledge of hydrology is important in managing water, particularly irrigation. The extent of knowledge required depends on the scale of irrigation. For example, low-level hydrological analysis may be good enough for small-scale irrigation because the variation of stream discharge from the mean is not significant. For large-scale irrigation design, a high degree of data accuracy is required because the variation of discharge from the mean is significant. Therefore, the need for detailed accurate hydrological information justifies long-term collection and recording of data over an extended period to derive robust statistics (Fenemor *et al.* 2003).

Hydrological information for water management can be captured in simple or complex ways, depending especially on the information demand and resources of the system. In smaller schemes, a simple water balance model can be used to establish the inputs, throughputs and outputs and the fluxes at each point. This balance analysis can help to explain how human activity and hydrological processes will affect throughputs or outputs. A more complex analysis can help in understanding the input and throughput influences on outputs in a complex system such as a linked multi-aquifer-river. With a catchment facing multiple and intensifying demands for water, a predictive model that includes water allocation options is essential for sustainable management. Another important use of hydrological information is to predict cumulative effects on water resources: a spatially explicit model is required to develop water allocation policy for drought or low-flow season to help ensure equitable allocation among users. Hydrological information has become indispensable for developing water management policy (Fenemor *et al.* 2003).

Hydrological information and knowledge can include all the water-related variables required for more complex decision-making in IWRM. Hydrological data are essential for the government's investment in water sector planning. Several data collection approaches have been suggested by Shaw (1994). Hierarchical hydrometric monitoring can be used, with primary, secondary and tertiary sites across the catchment. A continuous flow record is required at primary monitoring sites, and then a less intensive record may be considered at secondary sites and spot flow gauging at tertiary sites. Subsequently, correlation techniques for secondary and tertiary sites could be generated from primary sites that have similar hydrological characteristics.

There are two aspects to consider in determining what hydrological data are needed. Stream flow management is one objective. Data collection may be balanced between targeted (short-term) investigation and long-term baseline data. To quantify water resources, there is a need for adequate data to characterise variability over time and space. Rain gauges, stream flow and groundwater monitoring with geographical information system tools may allow for the geographic effects of topography and weather. Based on an understanding of water quantity and quality, the pressure on the catchment can be evaluated. Monitoring water use, including pollution and indirect pressures such as land-use change, is important in water resource planning (Fenemor *et al.* 2003).

Another aspect that determines what hydrological data are needed is water allocation. To allocate water, it is first necessary to know how much water is in the river and its variation over time. This is a technical issue, but water allocation also depends on identifying constraints and taking into account environmental safeguards; i.e. quantitative and qualitative biophysical and socio-economic factors should be considered. These safeguards may be derived from scientific enquiry or from legal, political or economic values, depending on what level of optimisation of water use is decided upon to balance the constraints on policy decisions. A common subjective judgement of various water user sectors, including irrigation, domestic water supply, fisheries and other ecological needs, can be made through a participatory decision-making process to set the limits of water allocation (Fenemor *et al.* 2003).

3

Methodology

This study focuses on the Stung Chrey Bak catchment in Kompong Chhnang province. It employed two methods: a *hydrological analysis* of spatial and temporal water distribution, and a *participatory learning and action* (PLA) approach to explore the problems and solutions concerning water allocation.

The research particularly involved the FWUCs in the four irrigation schemes, the Kompong Chhnang PDOWRAM and national line ministries such as MOWRAM and MAFF. Participatory learning and action has also enabled active engagement between the researchers and FWUCs, farmers and other stakeholders through tools such as the focus group discussion and semi-structured interviews.

3.1 Hydrological Analysis

Hydrological analysis is to inform decision-makers and water resource managers on the hydrological cycle and the impacts of economic activities on the environment. Informed decision-making weighs the advantages of a proposed development against the possible negative consequences and helps design appropriate mitigation measures (Ward & Elliot 1995).

This type of analysis requires hydrological and meteorological data. Information gathering starts by building up a data collection network. Participatory hydrological data collection and analysis methods are applied with a view to:

1. deepening understanding about supply-demand relationships and how they contribute to improving water allocation and optimising decision-making between schemes for more equitable access to water and water sharing;
2. enhancing the capacity of FWUC members and PDOWRAM staff in hydrological monitoring and water management through their participation and collaboration in this research project; and
3. designing a methodological framework for participatory research on water resources management in Cambodia.

As this research emphasises capacity building and knowledge sharing, the participatory field data collection methods and analysis are documented.

The study has increased hydrological knowledge and demonstrated participatory hydrological research. It used only the rating curve for estimating stream discharge. The rating curve analysis will provide a better understanding of water allocation in the catchment. The data collection procedure is described in the following section.

3.1.1 Participatory Hydrological Data Collection

Hydrology has spatial and temporal variations but it can be quantified through time at a fixed location using measured time series data. Analysis using time series data is achieved by statistical means or data modelling.

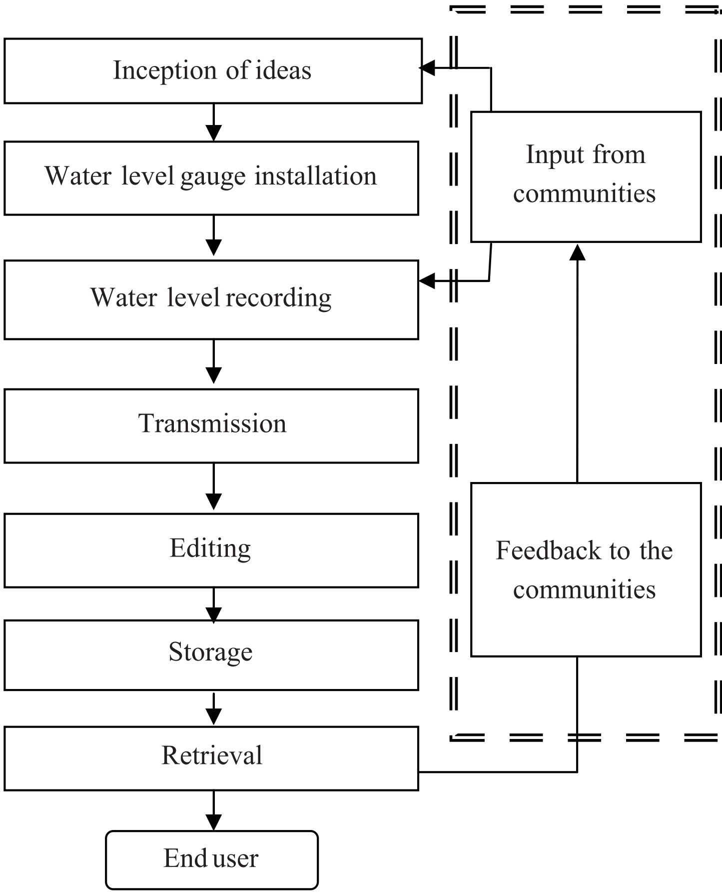
Hydrological assessment requires field reconnaissance to gain a general understanding of the catchment and a data scoping exercise to ascertain such things as length of records, methods of data collection, data integrity, data accuracy and data scale. The local communities were involved in all stages of data collection, including positioning the water level gauges, collecting rainfall and water use data, monitoring and recording data. Collaboration between the researcher and the community improves the knowledge base on stream flow distribution pattern within the sub-catchment. Such an approach ensures communities' ownership and improves the skills required for effective water management at community level.

The processes for this research are illustrated in Figure 1.

Figure 1: Water Level Gauge Installation and the Sequence of Participatory Hydrological Analysis

(a) PDOWRAM Staff at Scheme 1

(b) FWUC Members, PDOWRAM Staff and Researcher at Scheme 4



(c) Participatory Hydrological Analysis Processes (Modified from Chow *et al.* (1998) cited in Kongo et al. (2007)

3.1.2 Stream Discharge Estimation Using Rating Curve

The discharge of a river is an indispensable parameter for analysing hydrological features, quantifying the volume to be stored in dams or reservoirs and calibrating rainfall-runoff models. The discharge at a station can be obtained by measuring flow velocity, height and cross-section. However, measurement of flow velocity is not always possible and is time consuming, expensive and dangerous, especially during high flows (Jain & Chalisgaonkar 2000; Moramarco *et al.* 2004; Tayfur *et al.* 2007). Traditionally, a rating curve is used to estimate the discharge (Chow 1964;

Maidment 1993; Herschy 2008). A rating curve is a graphical presentation of the measured discharge plotted against the corresponding water levels (Shaw 1994). In this study, a rating curve is developed for evaluating the water resources potential of the Stung Chrey Bak stream. Rating curves [4] are established through simultaneous measurements of water level and discharge, with the results being fitted graphically using regression analysis. A rating curve is usually represented by the following general rating equation (Kennedy 1984):

$$Q_i = a\left(H_i - H_o\right)^b$$

Where Q_i is the discharge ($m^3\ s^{-1}$); H_i is the water level (m); a and b are constants; and H_o is the water level (m) at which the discharge is zero and below which the discharge is not feasible. The values of the constants can be found by fitting a curve to the measured data using a regression analysis, the least squares fitting technique.

3.1.3 Performance Evaluation

The performance of the rating equation developed in this study is assessed using various standard statistical performance evaluations. The statistical measures considered are root mean square error (RMSE) and coefficient of determination (CODE).

The following notations are used in the statistical measures: Q_i^e and Q_i^o are the estimated and observed discharges ($m^3\ s^{-1}$), respectively; Q_m^e and Q_m^o are the means of the estimated and observed discharges ($m^3\ s^{-1}$), respectively; n is the number of data pairs. The best fit between the estimated and observed values would have RMSE = 0.0 and CODE = 1.0.

Root mean square error (RMSE) is defined as the square root of the average of the square of the error of the estimated and observed values. Scores are negatively-oriented, i.e. lower values are better.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(Q_i^o - Q_i^e\right)^2}{n}}$$

The coefficient of correlation of the estimated and observed values (random variables) is expressed as the ratio between their covariance and the product of their standard deviations (Korn & Korn 2000). The squared value of the coefficient of correlation (R^2) or coefficient of determination (CODE) is usually used for interpreting the correlation.

$$\mathrm{CODE} = \left(\frac{\sum_{i=1}^{n}\left(Q_i^o - Q_m^o\right)\left(Q_i^e - Q_m^e\right)}{\sqrt{\sum_{i=1}^{n}\left(Q_i^o - Q_m^o\right)^2}\sqrt{\sum_{i=1}^{n}\left(Q_i^e - Q_m^e\right)^2}}\right)^2$$

Figure 2: Chiprong Water Level Gauge, Takab Village

4 Rating curves here refers to those of a general natural river rather than rating curves established at a measurement structure (measuring weir or flume) which are theoretically determined based on the geometry of the structure.

3.1.4 Rice Crop Water Requirement

Catchment planning needs to estimate rice crop water requirement, simply called consumptive use. It is actually the sum of the water infiltrated into the soil and the water evaporated into the atmosphere from adjacent soil and through transpiration (Garg 1999).

There is no rain in the dry season. Therefore, all water is provided through irrigation. Since meteorological data in the study area is inadequate, the consumptive use of a model plot of rice at Trapeang Trabek irrigation scheme was monitored. A sample of the field record sheet is presented in Figure 3.

Figure 3: Field Record Sheet

Name of Recorder: .... Plot number: ..... UTM [a/]: .... 48P: .... Plot area (m^2): ....

Number of records	Date	Time (hour: minutes)		Water depth (centimetres)		Comments
		Start	End	Start	End	
1						e.g. sowing
2						e.g. draining
3						e.g. 1st irrigation
10						Harvest

[a/] UTM is Universal Transverse Mercator. 48P is a positioning point in GPS that can mark and plot the point on a map

3.2 Catchment Water Allocation Problem Analysis

3.2.1 Survey Questionnaire

In addition to hydrological analysis, the research tried to understand water allocation within the four schemes. It adopted the International Commission for Irrigation and Drainage checklist, developed for rapid and low-cost feasibility studies and assessment of small and medium irrigation schemes in sub-Saharan Africa. The process and criteria used in the checklist are applicable in Cambodia (Aruna Technology Ltd. 2006). The questionnaire checklist comprises irrigation scheme information, preparation data sheet and field data sheet. A summary of the checklist is shown in Table 3.

Table 3: Preparation and Field Data Sheets

Preparation Data Sheet Information	Field Data Sheet Information
P1 Topographic data	F1 Socioeconomic background
P2 Previous investigations	F2 Environmental aspects
P3 Irrigation schemes in the locality	F3 Topography and soils
P4 Environmental aspects	F4 Agriculture
P5 Socio-economic aspects	F5 Water demand
P6 Geology and soils	F6 Surface water resources
P7 Climate	F7 Groundwater (shallow) resources
P8 Agriculture	F8 Supply and demand balance
P9 Sub-catchment water demand	F9 Irrigation infrastructure
P10 Hydrology of supply source	F10 Economic indicators
P11 Hydrogeology of supply source	F11 Development and operation

The data preparation sheet provides background information and technical data for field visits. This stage required desk review of reports and data to identify possible problems and areas where knowledge is lacking. The field data sheet was used to check the physical context that determines the parameters of the study. The information was used to complete the checklist.

3.2.2 Participatory Rural Appraisal and Participatory Impact Pathways Analysis

Participatory rural appraisal techniques, including focus group discussions, irrigation system mapping, problem analysis and semi-structured interviews, were used to gather information regarding water allocation problems and solutions. The techniques were used to capture pressing issues and possible solutions proposed by the communities. The short guide questions provided guidance to the focus group discussions and the semi-structured interviews with farmers, FWUC members and PDOWRAM staff. Altogether, 10 group discussions, approximately 10 people per group, were conducted in four irrigation schemes. Irrigation infrastructure was mapped using geographical information system.

Three commune and provincial consultation workshops were conducted. The workshops used participatory impact pathways analysis. The participants were FWUC members, commune councillors, district governors, the PDOWRAM, provincial departments of Agriculture, Forestry and Fisheries, of Environment and of Rural Development, and non-government organisations such as the Lutheran World Service and World Vision. The method allowed participants to analyse problems, propose new stakeholders and develop a logical model of impact pathways (see Table 1).

4

Case Study

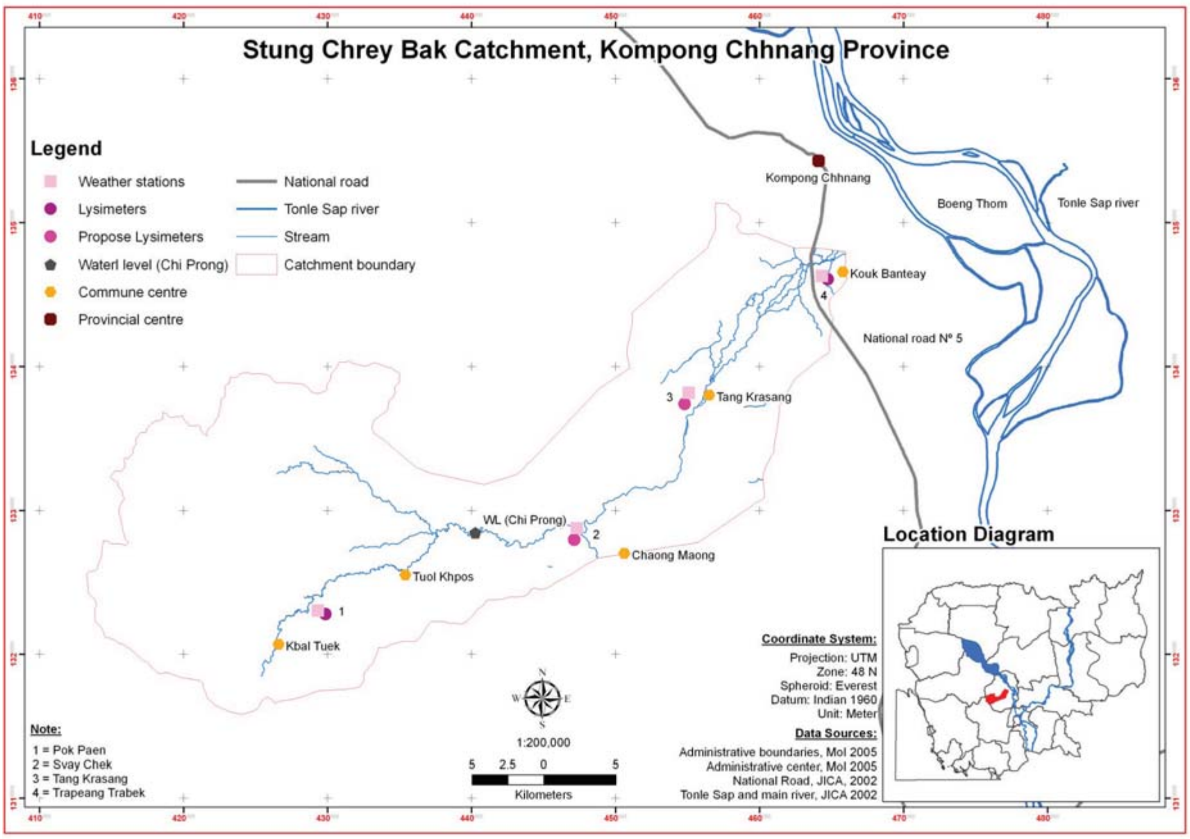
4.1 Overview

The case study for the physical research component is Stung Chrey Bak catchment, south-west of Kompong Chhnang town. In the catchment, a stream of 80 km originates in the Cardamom Mountains and crosses the catchment to the Tonle Sap River near Boeng Thom. Local people call the stream by different names. The upstream part is called Stung Srae Bak, the middle part Stung Kongkea and the downstream part Stung Chrey Bak or Stung Cheung Kriev. There is another tributary called Stung Chaktuem that connects to Stung Srae Bak at Chi Prong confluence (Ta Kab village). The main stream runs across two districts, namely Tuek Phos and Rolea B'ier. The area of the catchment is approximately 791 km^2.

4.2 Map of Study Area

The digital map of the catchment is derived from the 1:100,000 digital map of Cambodia It includes physical and administrative features including roads, rail lines, drainage, localities, contours and land use (Figure 4). The delineation of the catchment boundary takes into account natural and artificial physical features. The topography of the stream is characterised by three slopes: 0.37 percent for 16 km from the origin, 0.11 percent for 39 km in the middle reach and 0.09 percent for about 25 km to the south.

Figure 4: Hydrological Map of Stung Chrey Bak Catchment



4.3 Climate

Meteorological data on the catchment is lacking, but it is very close to the Tonle Sap Lake. Therefore, climate information is derived from the Tonle Sap Lake catchment. This catchment is influenced by the tropical monsoon and has two distinct seasons, the dry season from December to May and rainy season from June to November. During the rainy season, the south-west monsoon from the Indian Ocean brings about 80 percent of the annual rainfall.

The temperature across the lake catchment ranges from a mean daily minimum of 19°C in January to a mean daily maximum of 36°C in April. There is very little variation across the region, differences being in the order of 1°C. The mean annual temperature is 28°C. The lake experiences high humidity, with mean annual values ranging from 69 percent at Pursat to 79 percent at Phnom Penh. The lake rarely experiences humidity below 65 percent throughout the year. The records indicate a variation in mean wind speeds across the catchment, the south (Pursat) experiencing much lower winds than the north (Siem Reap) and south-east (Phnom Penh). Mean wind speed ranges from 0.5 m per second in the south to 4.4 m per second in the south-east.

Average solar radiation is 17.5 mega joules per square metre per day in the catchment. An average of about 7 hours of sunshine is recorded, with little regional variation. As would be expected, there are fewer sunshine hours in the rainy season, with an average of 5.5 hours at Phnom Penh and 7.4 hours at Siem Reap, compared to the dry season, 6.9 hours at Phnom Penh and 8.0 hours at Siem Reap. Rainfall in the catchment peaks in June–July and September–October. In July–August, a short period of drought may damage wet season crops that are not irrigated. Mean annual precipitation and evaporation are 1593 mm and 1591 mm at Phnom Penh, 1414 mm and 1344 mm at Pursat, and 1415 mm and 1625 mm at Siem Reap. Evaporation is usually highest in April.

4.4 Irrigation schemes

From upstream to downstream, the four irrigation schemes are Pok Paen, Svay Chek, Tang Krasang and Trapeang Trabaek, and are referred to in this order as schemes 1 to 4. Detailed information on each scheme is presented in Table 4.

Table 4: Irrigation Status of the Catchment

Irrigation schemes	Command area (hectare)		Households	Villages	Communes	District name
	Wet season	Dry season				
Scheme 1	621	-	300	6	1	Tuek Phos
Scheme 2	1800	-	3800	10	2	Tuek Phos
Scheme 3	5500	22[a/]	7500	30	5	Tuek Phos
Scheme 4	70	510	674	5	3	Rolea B'ier
Other	-	200 [b/]	-	2	1	Rolea B'ier
Total	7991	732		53	12	2 districts

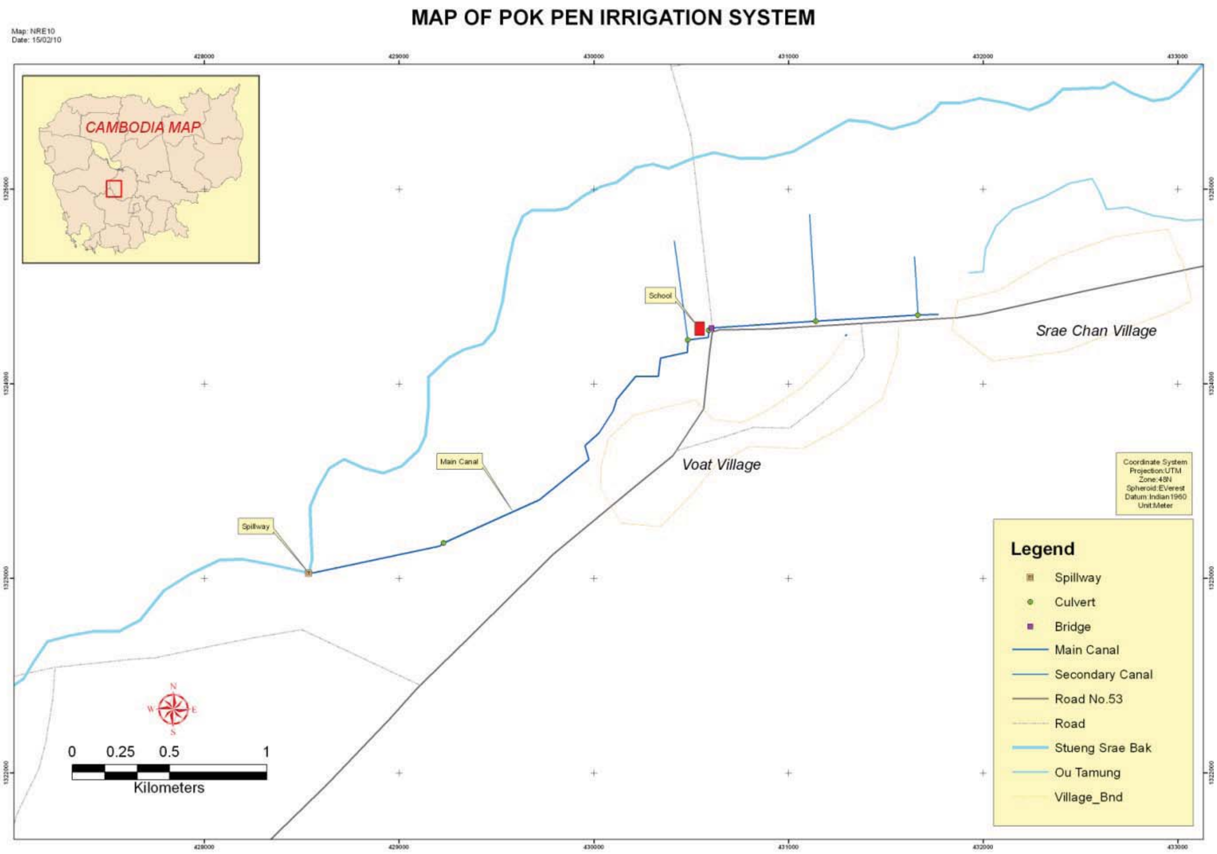
[a/] It is not clear how many more hectares will be cultivated in the future. [b/] 200 hectares were reported for Chrey Bak commune. The diversion structure of the Chrey Bak irrigation scheme is made of wood across the stream, located upstream from the Trapeang Trabaek scheme.

4.4.1 Scheme 1: Pok Paen

Scheme 1 is a medium irrigation scheme.[5] It is a stream-diversion weir with no storage capacity. The weir raises the stream level enough for water to flow into the main canal for supplementary irrigation in the wet season. It was started in 1969 but construction is yet to be completed. The water in the main stream is diverted to a feeder canal by a temporary barrage made of blocks of wood and stones.

The scheme was rehabilitated in 2005 by PDOWRAM, and a FWUC was formed in the same year to take over the responsibility for the scheme. It consists of a diversion weir and main and secondary canals. The area of wet season rice cultivation has increased from 250 hectares prior to 2006 to 620 hectares in 2009. The farmers in this area do not grow dry season rice because water levels in the canal are too low. Farmers whose lands are located a few hundred metres from the main canal's head cannot access irrigation water because their lands are higher than the canal's invert level. These areas account for about 30 percent of the total land area.

Figure 5: Map of Scheme 1



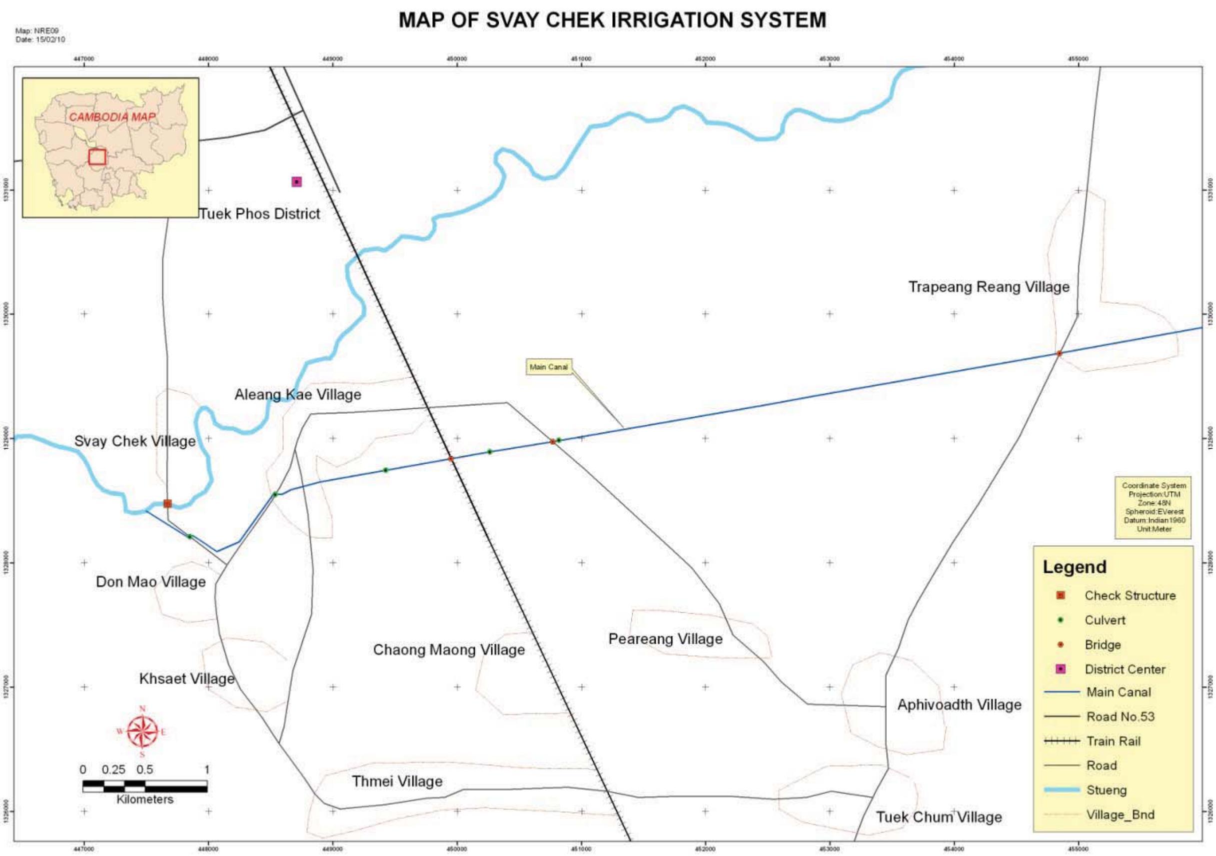
5 A small scheme irrigates 200 hectares or less, a medium scale scheme between 200 and 5000 hectares, and a large scale scheme more than 5000 hectares.

4.4.2 Scheme 2: Svay Chek

Scheme 2 is also a medium system. It is also a stream-diversion weir with no storage capacity. Its function is to raise stream water enough so that the water can flow into the main canal for wet season supplementary irrigation.

A wooden structure was built sometime around 1973. It is not known if the scheme was functional or what it was used for at that time. Farmers reported that about 100 hectares of dry season rice were cultivated during 1975 to 1979. In 1981, a new wooden structure was positioned in the stream. Local people were recruited to go into the forest to collect logs and build it. It was rehabilitated again by the American Friends Service Committee (AFSC) in 1989. At that time the scheme supplied water for supplementary wet season rice. In 2005, the water gates were built by the World Food Programme and the commune development fund.

Figure 6: Map of Scheme 2

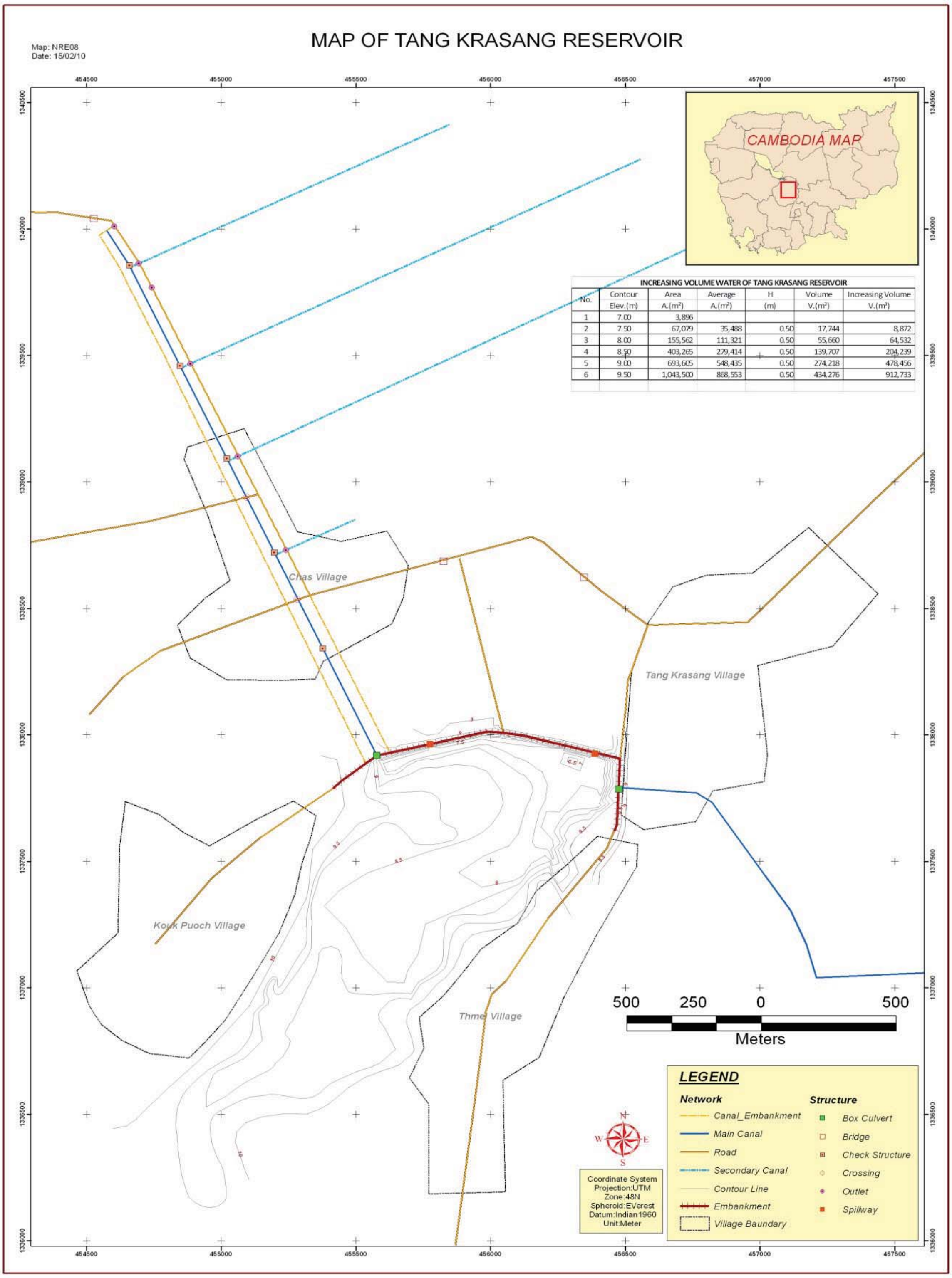


4.4.3 Scheme 3: Tang Krasang

Scheme 3 is a large irrigation system. It is an earth dam, built across the Stung Kongkea (Figure 7) to create a reservoir. The water is used for irrigation, households' and public school's water supply, drinking and bathing and livestock.

This scheme was built in 1976 and rehabilitated by the AFSC in 1985. It was renovated again in 2001 by PRASAC (Programme de Réhabilitation et d'Appui au Secteur Agricole du Cambodia). The scheme consists of a dyke, main canal, head-canal sluice structures and two spillways. However, the reservoir does not do a good job of mitigating fluctuating volume of water because it covers only about 279,000 m^2 on average, with a mean depth of about 1 metre (compared to the elevation of the spillway crests). In the wet season the scheme is often threatened by flood due to the large amount of rainfall in the catchment and the reservoir has sometimes overflowed (before 2001), but there is barely any water in the reservoir in the dry season, and only a small stream to replenish it.

Figure 7: Map of Scheme 3



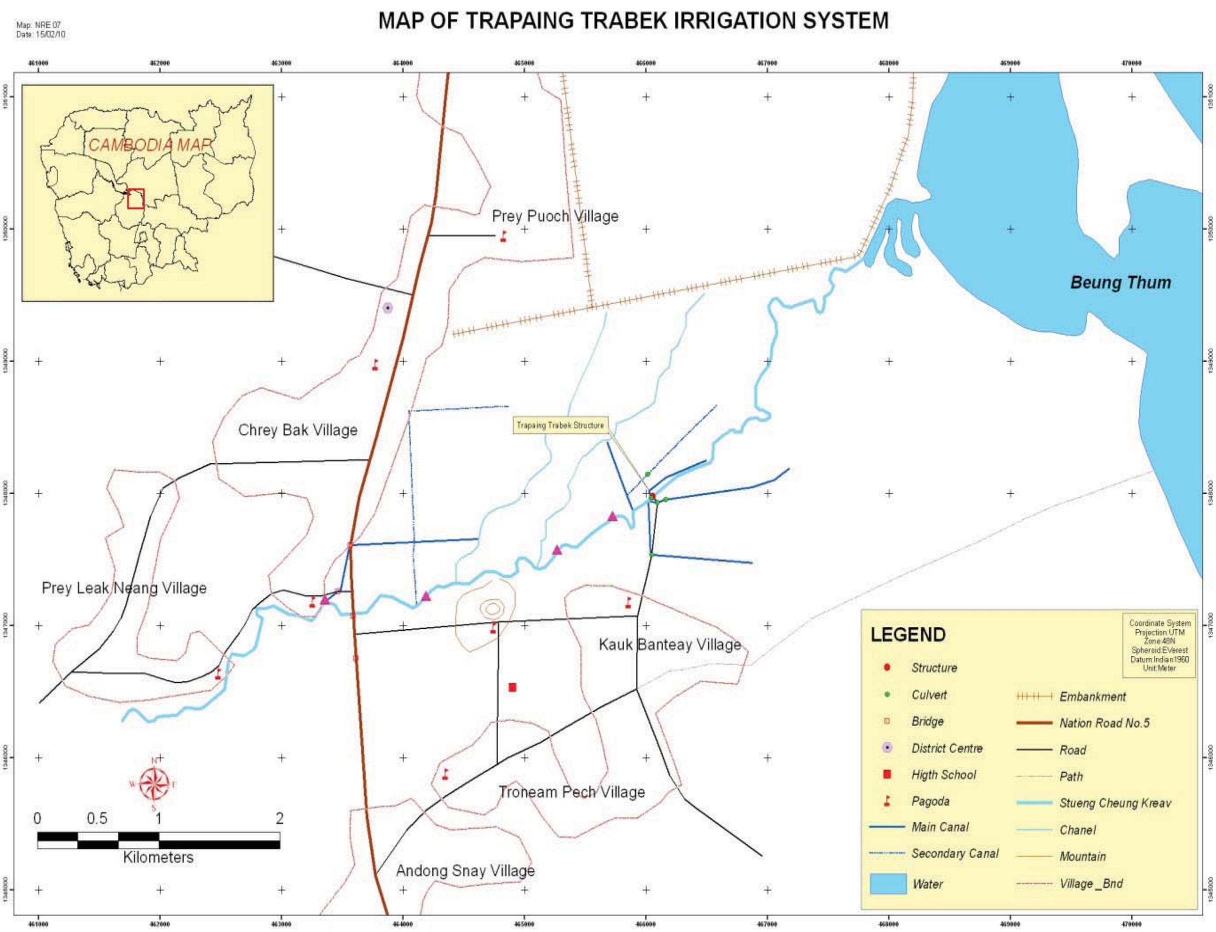
4.4.4 Scheme 4: Trapeang Trabek

Scheme 4 is a medium irrigation system (Figure 8). It is a stream-diversion weir with very small storage capacity located on the flood plain of the Tonle Sap River. It is submerged for most of the wet season. Before the scheme, local farmers could grow only floating rice and highly fluctuating floodwater often destroyed their crops.

The first attempt to mitigate the impact of floodwater was made in 1987, when a water gate was built by an agriculture collective (*krom samaki*). Local farmers recalled the time in 1987 when the government dispatched dozens of tractors to help plough their fields. At the same time, a station was set up to pump water into the rice fields when needed. However, these attempts at irrigation management were not successful. The pumping station could not supply water because the station operators misappropriated the gasoline and assets for running the pumping stations. Without an adequate irrigation supply, the crops failed and the scheme was abandoned.

The weir was built in 1991 with funds and technical support from the AFSC, and significantly improved farmers' access to water. However, as the irrigated area expanded, ensuring equitable access to water by farmers became more and more of a challenge.

Figure 8: Map of Scheme 4



4.5 Cropping Patterns

Rice is the dominant crop in the catchment. Farmers in schemes 1, 2 and 3 mostly cultivate wet season rice, while those in scheme 4 mostly grow dry season rice.

Wet season rice is grown along the main canals in the areas above and below the reservoir. Farmers who grow rice above the reservoir mainly rely on rainwater. During the drought spells in the wet season, farmers had to pump water from the reservoir to irrigate their fields. Farmers whose paddy fields are below the reservoir were luckier since they could access irrigation. Wet season cultivation generally starts in May–June and harvest is in November–December each year, depending on rainfall. Farmers normally do their first ploughing in April or May. Transplanting is undertaken in June–August depending on the weather.

Farmers who cultivate short-term varieties can grow two crops per wet season. They start their first rice crop in late April or early May and their first harvest is in August–September. The second crop starts in August–September, and the harvest is in November–December, the same as the normal long-term wet season harvest.

Dry season paddy cultivation is different. The timeline of dry season cultivation (scheme 4) depends upon the Tonle Sap flood recession. Most cultivated areas are adjacent to and below the reservoir. Farmers in scheme 4 broadcast seed rather than transplanting seedlings. Most rice varieties have a 90-day growing period. Farmers start sowing in mid-November. The latest harvests are in April.

4.6 Institutional Arrangements for Managing Irrigation Systems

MOWRAM is responsible for water development and management. PDOWRAM is responsible for water development and management including irrigation and catchment management at sub-national level and reports directly to MOWRAM and the provincial governor.

The FWUC was initiated by MOWRAM to take over the responsibility of managing the irrigation system (Article 19 Law on Water Management). The FWUC as a participatory community-based irrigation management organisation or local irrigation system governance entity is to have its own financial resources by administering irrigation service fees and receive technical support from MOWRAM through PDOWRAM. The FWUC is responsible for the daily operation and maintenance of the irrigation system and is to receive support from local authorities, especially commune councils.

All four irrigation schemes have informal FWUCs that work directly with commune councillors for decision making on water allocation and maintenance of the irrigation systems. The FWUCs themselves do not have financial and technical capacity to independently operate the schemes. MOWRAM and PDOWRAM provide some training in irrigation management and other technical, managerial and financial management skills to FWUCs.

Below is a summary of the roles and responsibilities of MOWRAM, PDOWRAM and FWUC in relation to water resources management.

MOWRAM	PDOWRAM	FWUC
Water law and policy development	Oversee and coordinate roles	Prepare the work plan for the committee Formulate the statutes, contracts and internal regulations of the community
Water resources inventory and planning	Provide framework for provincial and sub-provincial development committees in water-related development (water supply, sanitation, and small scale irrigation).	Maintain the regulation system in good condition to enable the provision of irrigation for the whole production season
Ensuring effective and sustainable management and operation of the irrigation system, through initiating creation of FWUCs		Manage and distribute water to all members - Strengthen the use, maintenance, and improvement of the irrigation system in an efficient manner - Resolve the problems occurring within the community - Collect irrigation service fees (ISF) from members.
Water resources use and development through water licensing mechanism		
Water resources protection and flood protection.		

5

Results and Discussion

The physical component research has generated knowledge on stream discharge, key issues related to irrigation management and upstream-downstream linkages.

5.1 Stream Discharge at Chiprong (Takab Village)

Stream discharge and water level measurements were taken by the Department of Hydrology and River Work (MOWRAM) at Chiprong hydrological station (Ta Kab village). These measurements were used to establish the rating equation for the observation site only. The rating equation is $Q = 13.259\ (H - 0.375)^{2.029}$. The rating curve was used to estimate the discharge of the main stream. The accuracy of the rating equation was assessed based on a comparison of the estimated and observed stream discharge. The results of the rating curve analysis are shown in Figures 9 and 10. Backwater effect was not clearly observed at the measurement site.

The performance of the rating equation is clearly shown on the scatter plot (Figure 10). The discharges estimated by the equation are relatively close along the slope-one line with low RMSE (3.806 cubic metres per second) and high CODE (0.979). The rating equation estimates the low flow discharge with high accuracy and the high flow discharge with fairly good accuracy.

Figure 9: Rating Curve of the Stung Chrey Bak (Takab Village)

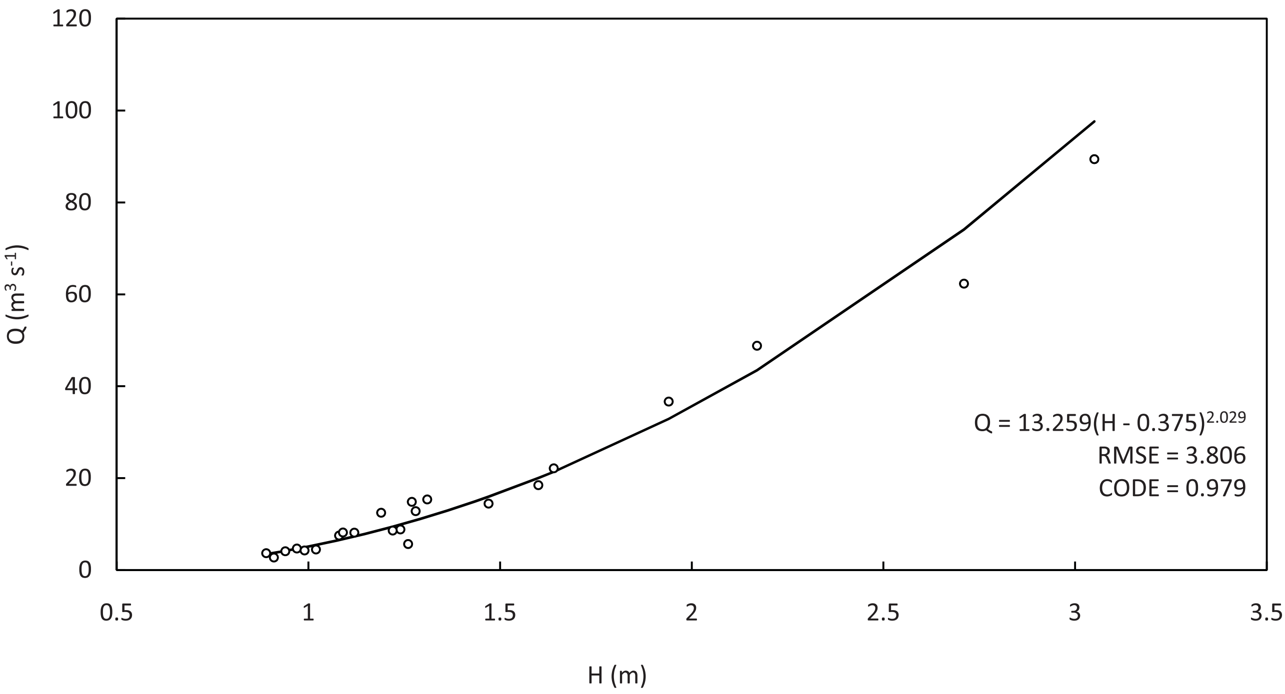
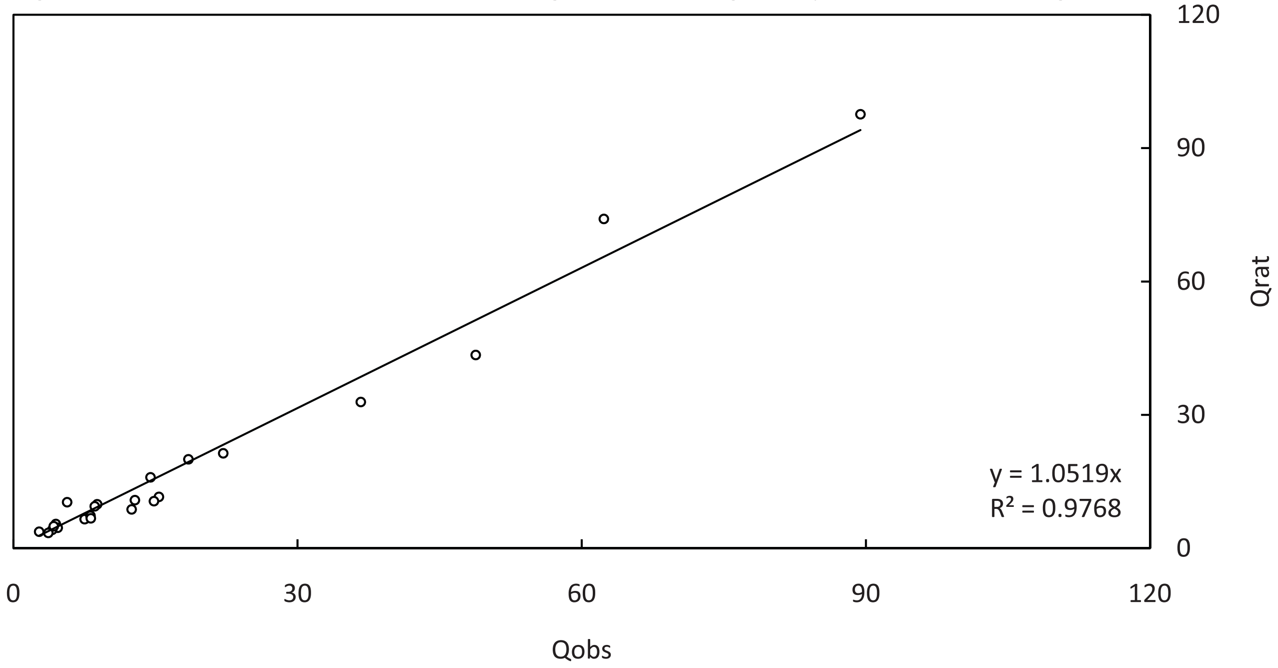


Figure 10: Rated versus Observed Discharge of the Stung Chrey Bak (Takab Village)



Water availability (or monthly run-off) is defined as the amount of water in the main stream over a period of time. Water availability at the monitoring site was estimated using the rating equation. The daily hydrograph of the stream is illustrated in Figure 11, and water availability from the catchment is shown in Figure 12. Annual run-off is about 284 million cubic metres, 89 percent of which occurs in the wet season. Peak flows usually occur in September–November, accounting for about 58 percent of the total annual run-off.

Figure 11: Hydrograph of the Stung Chrey Bak (Takab Village)

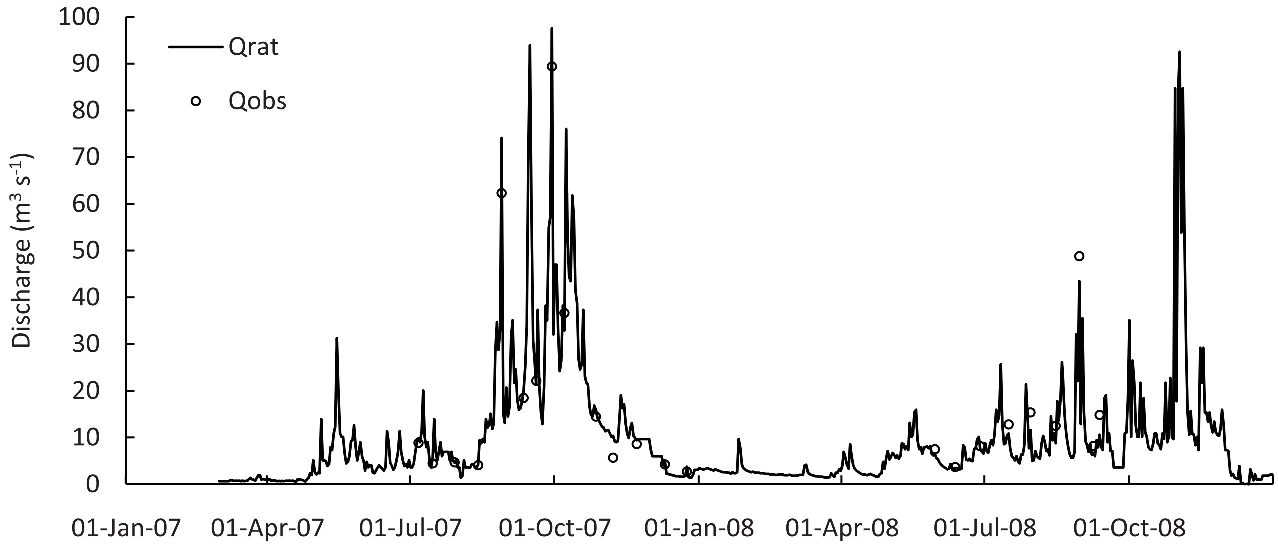
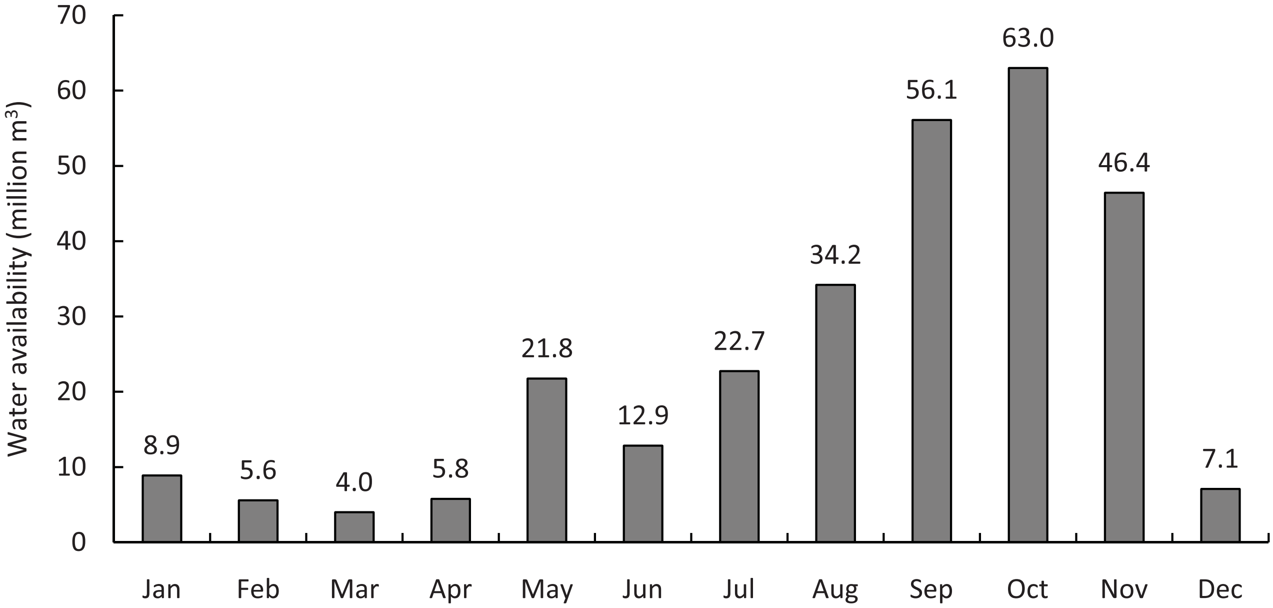


Figure 12: Water Availability of the Stung Chrey Bak Catchment



5.2 Rice Crop Water Requirements

Since data on the rice crop water requirement in the study area was not available, data on the water requirement for dry season cultivation of early rice varieties (105 days) on the Tonle Sap Lake floodplain, which ranges from 560 mm for silt paddy field (Someth *et al.* 2009) to 986 mm for sandy loam paddy field, was used to evaluate the irrigable area (Someth *et al.* 2007). Water availability from the Chrey Bak stream was estimated using the rating curve. The results were then used to estimate the potential area of rice that could be irrigated by the stream. Water withdrawal from the stream during the rainy season was considered. The average low flow from December to April (6.3 million cubic metres) was assumed to be the minimum flow required to sustain the ecosystems of the main stream. Water withdrawal was calculated as the difference between water availability and low flow. The total possible withdrawal was found to be about 191 million cubic metres, which is 86 percent of the total water available in the rainy season (222 million cubic metres). Given the rice crop water requirement, the total withdrawal could irrigate 19,000 to 34,000 hectares (no loss included).

5.3 Irrigation Management

5.3.1 Scheme 1

Farmers in scheme 1 do not grow rice during the dry season because of water shortage. This scheme was designed for supplementary irrigation during the wet season using early rice varieties. Rice can be grown twice in the wet season (April/May-August/September and August/September-November/December).

This scheme is operated by the FWUC, which is responsible for providing irrigation water to its members and collecting the irrigation service fee (ISF) for operation and maintenance. However, hardly any ISF is collected. Lacking adequate funds, the FWUC members work voluntarily. When the canals and regulators need to be repaired, the FWUC appeals for labour contribution from members and financial support from donors. Usually, the FWUC collects hardly any free labour or only small monetary donations from members for the repair work. As a result, the canals and regulators have never been properly maintained. However, during big floods, the FWUC receives sandbags from the PDOWRAM to repair the canal temporarily. During extreme drought, the FWUC is given petrol and pumps to pump water from the stream into the main canal.

In regard to access to water, about 30 percent of the command area cannot access gravity irrigation because the land is higher than the water level of the main canal. PDOWRAM is aware of this issue but can do little to help. The other 70 percent of the command area can access gravity irrigation. Apart from this physical limitation, the lack of infrastructure, especially regulator and secondary and tertiary canals makes it difficult for the FWUC to allocate water equitably. Irrigation is normally rotated from one village to another.

5.3.2 Scheme 2

Farmers in scheme 2 mainly grow wet season paddy. Similarly to scheme 1, land located along the main canal near the stream-diversion weir is unsuitable for gravity irrigation because it is too high. In addition, the soil in that area cannot retain much water, which drains back into the main canal if farmers do not manage their bunds well. The situation is made worse by the porous nature of sandy soil as leaking water leaches fertiliser from the fields. Dry season rice has not been cultivated in this area since 1979. In the dry season farmers resort to supplementary sources of income such as palm sugar production, logging and collecting firewood. Some people go to work in Pailin or garment factories in Phnom Penh.

There is no FWUC in scheme 2. The stream weir is operated by a village chief who is the gatekeeper in charge of allocating water, which mostly irrigates the land along the main canal. When farmers need water, they make a request to the commune chief, who then informs the gatekeeper of their needs. Sometimes, after notifying the commune chief and the gatekeeper, the people have to open the gate themselves.

Although the water used in scheme 2 affects the water flow to schemes 3 and 4, the gatekeeper does not seem to be aware of what happens downstream. His main responsibility is to make sure that the people in the immediate locality have water for their needs. In the dry season, the water gates are generally closed (especially in January and February) to maintain the desired level. In the rainy season, more gates are opened to release excess water. However, the gatekeeper has to constantly monitor the rain in the catchment.

5.3.3 Scheme 3

Farmers in scheme 3 grow both wet and dry season rice, but wet season cultivation is dominant. The few attempts to cultivate rice during the dry season did not produce good harvests due to severe insect infestation and water shortage. This year, farmers tried new rice varieties such as IR 66, Saen Pidor and Chhlong Daen for dry season cultivation. The yield ranged from 0.9 to 1.5 tonnes per hectare. Five out of every 22 cultivated hectares yielded no harvest due to water shortage caused by the lack of secondary and tertiary canals.

This scheme is operated by one FWUC member who is now also a village leader. The FWUC had five members at the beginning of the scheme's rehabilitation. Farmers expected the rehabilitation to result in increased dry season rice cultivation. This would be a source of revenue for the FWUC, not just for salaries but also for the operation and maintenance of the scheme. However, the scheme does not have enough water for dry season cultivation. Without extra harvests in the dry season, the FWUC could not collect any ISF. As a result, the FWUC faces a shrinking membership. The remaining members already hold official positions such as village head or commune councillor. The head of the FWUC is now the commune chief. He has to take on this role because he has an obligation to his commune's development. Although farmers get supplementary irrigation from the reservoir for their wet season rice, they are not willing to pay the ISF because they perceive water as a public good, which should therefore be free.

Running the scheme is not easy. It is subject to damage by erosion and flood and requires regular maintenance. In times of flood surge, the members have to patrol the dam to detect vulnerable spots. When they find a weak spot, the FWUC asks the villagers for help, which is usually given in the form of labour. In the dry season, the FWUC has to open and close the gate in response to the requirements of farmers in the area.

5.3.4 Scheme 4

Farmers in scheme 4 grow only dry season rice. Irrigation management is the responsibility of the FWUC. Although the operation and maintenance of this scheme has had little success, the performance of the FWUC is fairly good.

Some ISFs are collected. Farmers who get gravity irrigation pay 20,000 riels per hectare per harvest and those whose land is watered half by gravity irrigation and half by pumping water pay 10,000 riels per hectare per harvest. In reality, however, farmers generally refuse to pay the ISF and always complain about the poor water provision and the ISF is paid in only a few areas.

The scheme was rehabilitated in 1991 by AFSC, and cultivation shifted from floating rice to dry season cultivation. The rehabilitation did not significantly increase dry season rice production immediately as only 30 hectares were being cultivated at the time. However, it resulted in a significant increase in dry season yields, an average of 3 tonnes per hectare compared to 1 tonne previously. This motivated local farmers to convert from floating to dry season rice, resulting in a rapid expansion of the command area from 30 hectares in 1991 to 500 hectares at the time of study.

The over-expansion of the command area has led to irrigation water shortages. This was particularly evident in 2005 and 2006. Dry season rice cultivation generally starts in mid-November and finishes in March. The critical time is in February, when rice needs water the most. In February and March, the water level in the reservoir fell rapidly, causing a general panic among farmers. Normally, irrigation water would be rotated from one canal to another, but farmers simply ignored the allocation arrangement during the water shortage and frantically tried to pump as much water from the scheme as possible. The competition for water continued until all of the water had been extracted and the stream dried up.

5.4 Key Issues Relating to Catchment Water Management

The key issues are fragmented catchment management, increased areas under irrigation and lack of hydrological knowledge.

The FWUCs and PDOWRAM struggle to manage irrigation schemes because they lack knowledge of catchment management. Participatory and integrated catchment management takes into account technical, social and political factors to plan water resources management. Participation occurs during planning and allocation of water, while integration happens during multidisciplinary planning which involves experts from different disciplines (e.g. agriculture, fisheries, forestry, environment, social development). Thus, PICM should involve MOWRAM, MAFF, Ministry of the Environment, Ministry of the Interior, provincial and district authorities and commune councils and the National/Provincial Committee for Decentralisation and Deconcentration, Ministry of Public Works and Transport, Ministry of Health, Ministry of Economy and Finance and the FWUC as the local entity. This case study found that MOWRAM is the main institution involved in catchment management.

FWUC members for their part are expected to play important roles in scheme operation and maintenance, provision of irrigation service to beneficiaries, water allocation decision making, and planning and coordination with stakeholders. PDOWRAM officials are to provide technical and managerial support to the FWUCs. However, both entities failed to establish a proper mechanism or support to carry out catchment planning and irrigation management. Three main problems lie behind this failure: the increase in the demand for irrigation water, the fragmented management as a result of inadequate institutional arrangements and the lack of catchment hydrological knowledge.

Irrigated areas have significantly increased over the last 30 years due to population growth and irrigation infrastructure development. A growing population requires more economic activities, especially in the dry season when stream water is limited and the capacity of the reservoir is too small to meet demand. Many farmers who grow dry season rice lack irrigation. This is not only because there is not enough water in the catchment but also due to the lack of irrigation infrastructure and management mechanisms. Consequently, the delivery of irrigation water is not timely and water is unfairly allocated between schemes and between users within the same scheme. This creates intense competition for irrigation water. Unequal allocation between upstream and downstream users happens simply because there is a lack of water, and upstream farmers require water for domestic consumption, livestock as well as irrigation.

Farmers irrigate their land by flooding from one plot to another. This wastes a lot of water and deprives farmers in downstream areas of water. This causes many conflicts.

Current irrigation practices could potentially provide water for 800 hectares during the dry season if infrastructure such as canals and regulators were improved. The water requirement for 800 hectares of dry season rice is about 1.3 million cubic metres a month. This is less than the minimum stream flow in March, which is about 4 million cubic metres a month. The average discharge of the main stream is 6 million cubic metres per month from December to April. Water availability in the wet season is not much of a concern. The highest flow, up to 63 million cubic metres per month, occurs in September and October.

Based on the hydrological analysis, increasing the storage capacity within the catchment could solve water shortage. Previous attempts to raise the height of the river banks just upstream from the dam in order to store more water failed. Expansion of the scheme would require land that is presently occupied by farmers. Also, there is no money for expansion; the FWUC can barely collect enough revenue to cover existing operation and maintenance costs. Another attempt was to integrate irrigation expansion plans into the commune development plan, but this also failed because an irrigation scheme is perceived to be a semi-public property. Once a scheme is built, it benefits people in the village but not other villages. Therefore the commune development committee members who represent other villages vetoed the proposal to use the commune development budget to finance expansion of the scheme.

Fragmented planning and management arise from a lack of coordination. Irrigation development has been single-sector oriented and ad hoc. Schemes developed during the 1980s and early 1990s with assistance from international organisations aimed to increase agricultural production for household food security; in tandem, FWUCs were established to manage the irrigation schemes. However, development during these periods failed to establish a mechanism for catchment management. The FWUCs and commune councillors focused only on their own local schemes. Each scheme was individually planned without consulting the schemes downstream or upstream, leading to many of the command areas being over-cultivated. Some areas were damaged and dry season crops were lost due to the lack of water. In this situation, there was intense competition and conflict over the use of irrigation water. District authorities rarely communicated with FWUCs unless they were asked for help when conflicts occurred. The PDOWRAM has always helped to resolve conflict by looking at water availability in each scheme and trying to adjust the flow. But again, with limited infrastructure, financial and technical support, the PDOWRAM could not assist the FWUCs in an effective and timely manner. As a result, many farmers had limited access to irrigation, and the benefits were lost due to the lack of coordination between different users and FWUCs.

Irrigation management could be improved if communities were to actively participate in the process. However, this research found that while farmers 20 years ago would contribute labour and money to repair broken infrastructure, communities today find it difficult to get people involved in maintenance works without paying them cash. Social participation in irrigation management has declined over the last 20 years. Therefore, most repair work has relied on assistance from the PDOWRAM. However, PDOWRAM officials do not always help in time and infrastructure continues to be in disrepair. This has reduced the potential benefits of irrigation.

The limited capacity of the FWUCs and PDOWRAM in catchment management has weakened planning coordination between irrigation schemes. The roles of the PDOWRAM are to assist FWUCs in the operation and management of irrigation and to coordinate sub-national irrigation development and management. However, because it lacks financial and technical incentives, the PDOWRAM cannot perform its tasks well. This makes it harder for FWUCs to coordinate with each other. Without enough irrigation water for their fields, farmers are reluctant to participate in management or pay the ISF. Because of inadequate finances to support their activities, some FWUC members have dropped their roles, and newly established FWUCs have become dysfunctional. Thus, most of the FWUC roles in irrigation operation and maintenance and water allocation fall to the commune chiefs or village heads.

The lack of hydrological knowledge in the PDOWRAM and FWUCs specifically relates to dealing with water allocation and irrigation planning. Knowledge of the catchment processes that link water movements, communities and environments would help identify possible impacts of upstream development on downstream water users and solutions for upstream-downstream linkage. In order to build up hydrological knowledge, skills and data are needed. This research found that catchment management lacks both skills and data.

6

Conclusion, Recommendations and Way Forward

6.1 Conclusion

Access to water for irrigation is restricted by natural water limitations, the lack of irrigation infrastructure and limited human capacity in this field.

Insufficient water is a natural limitation of the catchment. None of the irrigation schemes in the Stung Chrey Bak catchment have significant storage capacity. About 191 million cubic metres can be withdrawn from the main stream during the wet season. This amount of water can irrigate from 19,000 to 34,000 hectares of early (105-day) rice.

Apart from the natural lack of water, the lack of irrigation infrastructure also limits access to water. Inadequate infrastructure gives rise to many problems for system operators and farmers in terms of providing the right amount water at the right time and place.

Catchment management is fragmented and lacks coordination between water users. This fragmentation is caused by the absence of a catchment management committee. Without such a committee, the FWUC members struggle to provide irrigation services and to communicate with other users and management. The current management in turn fragments rice crop and water allocation planning. Without proper planning, farmers have unequal access to irrigation, which then leads to intense competition over water.

Cambodia is moving from rain-fed to irrigation-oriented cultivation. Approaches to water management such as PICM and IWRM are needed for the sustainable development of the water sector. Although IWRM has been adopted and practised in some projects in Cambodia, its implementation is limited. IWRM is mainly donor-driven and managed by central government ministries. Current IWRM needs more capacity building for local water managers.

Hydrological knowledge plays important roles in effective catchment management, particularly infrastructure design and operation of irrigation schemes and water allocation. Not knowing how much water there is and when it is available makes it impossible for the PDOWRAM and FWUCs to allocate water properly. Therefore, lack of hydrological knowledge also causes conflict between users.

6.2 Recommendations

It is recommended that local expertise in water resources management be improved. This can be achieved through on-the-job and academic training:

- On-the-job training through participatory/active research could involve researchers, government officials and farmers. This should provide lessons to managers and local practitioners on problem

definition, methodology and practices for problem solving and the concept of IWRM appropriate for the locality.
- Academic training could be achieved through the research project's collaboration with national, regional and international academic institutions. The project should provide student internships as part of the research framework. Capacity building should involve researchers, government officials, local authorities, FWUCs and farmers.

Because of the natural limitation of water in the Stung Chrey Bak catchment, hydrological knowledge about spatial and temporal distribution of flows is very important to sustainable planning. Hydrologists need hydro-meteorological time series data. The recommendations in this regard are:

- Collection, observation and analysis of stream water level at Chiprong should be continued.
- Collection of data from reservoir water level gauges, which were installed in 2009 by CDRI at each scheme, should be maintained, including the collection of data from all rain gauge stations. A meteorological data are needed for catchment water balance analysis and catchment planning, especially for proper crop water requirement estimates. Stream flow rating curves and reservoir rating curves are needed for irrigation planning. This knowledge should be transferred to the FWUCs and PDOWRAM staff after the project is completed. All the data should be made available to FWUCs, PDOWRAM and MOWRAM staff, and researchers.

All physical irrigation infrastructure, including spillway gates, regulators, check structures and irrigation canals, should be rehabilitated.

Catchment development planning should be participatory and integrated. Participatory planning should include farmers, FWUCs, commune councils, district authorities, provincial authorities, provincial technical departments and related national ministries. Integrated planning should include all provincial technical departments.

Both FWUCs and the PDOWRAM play crucial roles in local irrigation scheme management, but they lack capacity in PICM. PICM could address the problems of the current management approach in the following ways:
- For single-individual irrigation scheme management approach, all four irrigation schemes need to be integrated in planning for cropping and water allocation. FWUCs alone have no capacity to achieve that. It needs the involvement of higher authorities and initiatives from MOWRAM, PDOWRAM, CDRI, donors, provincial governor and local authorities.
- A catchment management committee, chaired by an appropriate representative to steer a working committee, should be established. Such a working committee should include relevant provincial technical departments.
- Representatives from each irrigation system in the catchment should have seats on a working committee that is involved in water allocation.
- In order to achieve the broad goal of PICM in irrigation development, financial and technical support should be arranged for both FWUCs and the PDOWRAM.
- To maximise sustainability, PICM should be directly implemented by PDOWRAM with support from institutions such as MOWRAM and CDRI. CDRI should provide research-based recommendations and training.

A catchment data collection and monitoring network is needed. Again, a participatory approach is recommended and should be applied in the following ways:

- Participation in hydrological data collection should include defining types of data, how they can be collected, how they can be processed and why they are needed.
- Data collection should involve FWUCs that will benefit from participating. Participation would allow communities to identify problems and solutions themselves and to take ownership over the data and the knowledge they would gain to solve their problems.
- The researchers share new technologies with the FWUCs. Several steps can be recommended for carrying out PICM:

  - participatory establishment of a data collection network with the community;
  - applying multidisciplinary expertise in addressing identified problems, processing and analysing data and providing feedback to the community;
  - conducting a training course for improving the professional capacity of the researchers and communities, developing research methods and conducting in-depth pilot or case study research;
  - a catchment mechanism for resolving conflicts between water users.

6.3 The Way Forward

To cope with water limitations, farmers have wondered how they could use their water more wisely, better plan their cropping and better share their water resources equitably among different schemes. To address these concerns, water balance analysis and better community organisation are recommended. These two activities have to be implemented at the same time. Water balance helps identify how much water is available, how much is used, how much can be released and when that water should be released for downstream users.

The physical research component has developed the stream rating curve and identified the daily, weekly and monthly stream discharge, which is useful information for planning but is still not enough. More data, including water demand and supply at each irrigation scheme, are needed for a catchment water balance model. These data will help identify development scenarios and options. As a way forward from now until June 2011, the physical component proposes to:

- develop a catchment water balance analysis of the Stung Chrey Bak catchment, possibly using water evaluation and planning system software;
- develop and present a catchment water allocation principle based on the results of the water balance analysis and water allocation analysis;
- generate and recommend institutional arrangements for improving the performance of the FWUCs and PDOWRAM, drawing upon the results of the water allocation analysis and stakeholder analysis during the WRMRCDP's provincial dissemination and consultation workshops;
- help establish a meteorological data network in the catchment;
- make all collected and analysed data available to the public through a website and publications.

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