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HYDROLOGICAL ANALYSIS IN SUPPORT OF IRRIGATION MANAGEMENT

A Case Study of Stung Chrey Bak Catchment, Cambodia

CHEM Phalla, Philip HIRSCH and SOMETH Paradis

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Front cover photos:
1. Stung Chrey Bak stream, Kompong Chhnang province
2. Rice field in Pok Paen irrigation stream, Kompong Chhnang province

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ABBREVIATIONS AND ACRONYMS

AusAID	Australian Agency for International Development
CCs	Commune Councils
CDRI	Cambodia Development Resource Institute
CR	Crop Water Requirement
E	Evaporation
E-flow	Environmental in-stream flow
ETc	Evapo-transpiration of crop
FA	Forestry Administration
FiA	Fisheries Administration
FWUC	Farmer Water User Community
GDP	Gross Domestic Product
Ha	Hectare
IR	Irrigation Requirement
ITC	Institute of Technology of Cambodia
IWRM	Integrated Water Resources Management
MAFF	Ministry of Agriculture, Forestry and Fisheries
m^3	Cubic metre
MDBC	Murray-Darling Basin Commission
MIME	Ministry of Industry, Mines and Energy
MOE	Ministry of Environment
MOWRAM	Ministry of Water Resources and Meteorology
MRD	Ministry of Rural Development
MPWT	Ministry of Public Works and Transport
MT	Ministry of Tourism
NRE	Natural Resource and Environment
Pe	Effective rainfall
PDOWRAM	Provincial Department of Water Resources and Meteorology
PICM	Participatory Integrated Catchment Management
RGC	Royal Government of Cambodia
RUPP	Royal University of Phnom Penh
T	Transpiration
USYD	University of Sydney
WEAP	Water Evaluation and Planning System
WRMRCDP	Water Resources Management Research Capacity Development Programme

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SUMMARY

This study examines the possibility of supporting improved catchment irrigation management by evaluating scenarios based on sound hydrological analysis using the Water Evaluation and Planning System (WEAP). The scenarios identify clear options and practical implications for irrigation management which can inform policymakers and relevant stakeholders. These stakeholders include the Farmer Water User Communities (FWUCs), commune councils (CCs), and the Provincial Departments of Water Resources and Meteorology (PDOWRAM) who are currently in charge of irrigation management at community and provincial levels.

Contemporary changes in farming practices in Stung Chrey Bak catchment form the background to this study. Rice farming is changing rapidly from rain-fed mono-cropping to irrigated double or triple cropping. Seven irrigation schemes have been built to extract water from the stream so that the rice growing area of 10,367 ha (741 ha in the dry season) is no longer heavily dependent on rainfall. Dry season rice is grown mainly in the downstream area of the catchment where cultivation depends entirely on irrigated dry season farming because flooding during the wet season, and hence farmers here are entirely depend on dry season stream flow. Water shortages have led to some rice growing areas being damaged, and competition between water users in downstream irrigation schemes has been particularly intense in recent years, especially in the months of February and March. The rapidly growing demand for irrigation has created and intensified competition for water resources, raising concern about the equity of water allocation, sustainability of water usage, social friction among water-user communities, and long term sustainability of water resources and environmental impact of irrigation. In addition, traditional supply-based water planning is no longer appropriate. Instead, planning for water-supply projects should also focus on demand-side water management.

Government policy reform, including river basin management, is expected to address some of these concerns. However, sound water management requires good knowledge and applicable tools to support well informed decision-making.

The WEAP model incorporates the values of demand management into a practical applicable water resource planning tool for: (1) defining modelling problems; (2) establishing the current account, from which different irrigation demand management scenarios can be evaluated; (3) simulating scenarios; and (4) evaluating these scenarios against criteria such as water availability and environmental in-stream flow (e-flow) conditions.

Three demand management scenarios were developed for this study – reference, 5 percent annual increase in irrigation demand, and additional reservoir storage from scheme numbered 5. E-flow demand was estimated to be 30 percent of monthly stream flow. The e-flow demand was not included in the current account (2007). However, it is included in the three scenarios.

In 2007, stream flow was calculated at 289 million m^3 and the irrigated area was 10,367 ha. The lowest flow measured in the middle part of Stung Chrey Bak catchment was 4 million m^3 in March, 5.6 million m^3 in February, and 12.9 million m^3 in June.

The reference scenario simulation shows that this stream flow, without allowing for e-flow, is sufficient for irrigating a dry season rice growing area of 741 ha and wet season area of 9,626 ha. However, the catchment's water supply is not sufficient when the e-flow, water use by other sectors, livestock, and small rural industrial consumption, which are not included in

this study, are taken into account. There is an unmet demand of 4.2 million m^3, mostly in June (0.95 million m^3 in March).

The 5 percent annual increase in irrigation demand simulation shows that the irrigated area will have reached 16,083 ha by 2016. This would have two implications: (1) without considering e-flow, climate variability and other water usages, unmet irrigation demand will be 2.97 million m^3 mainly in June; (2) allowing for e-flow would increase unmet irrigation demand to 7.89 million m^3, mostly in June (1.3 million m^3 in March).

The additional reservoir storage scenario simulation shows that the reservoir capacity in irrigation scheme numbered 5 is small and can barely help improve unmet demand in times of drought. There are topographical and land acquisition constraints that reservoir storage cannot be enlarged.

Three patterns of stream flows were observed: dry season (November-April), wet season 1 (May-July: low flow) and wet season 2 (August-October: high flow). The variations of stream flow have implicated greatly on farming and ecosystem; i.e. low stream flow in March and June limits farmers from increasing their irrigating areas, and it causes environment degradation. The conclusion is that when taking into account the e-flow demand the irrigated area should be limited to 10,000 ha, including 740 ha in the dry season. Alternatively, when the e-flow is considered as a secondary priority; the irrigated area should not be expanded beyond 12,000 ha.

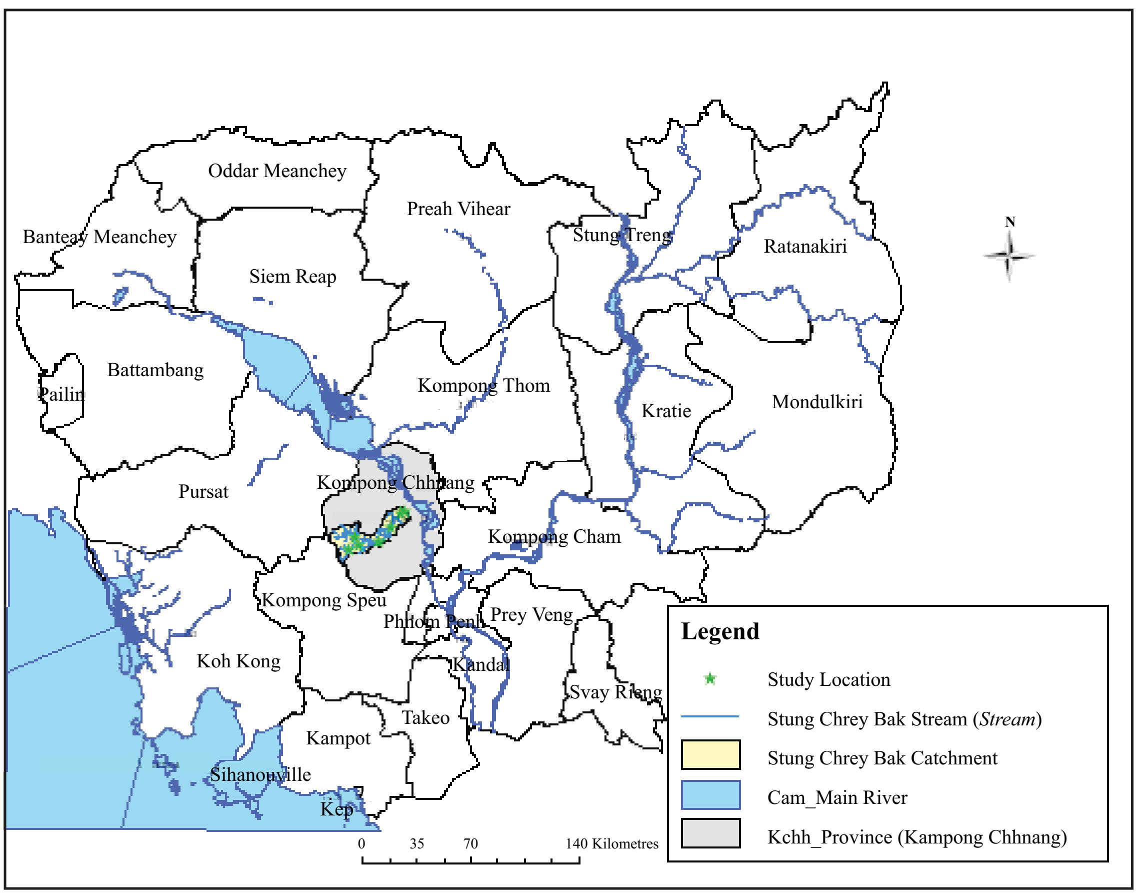
In a situation of water limitation, a harmonising crop planning between upstream and downstream cropping areas, bases on stream flow patterns, is crucial in optimising the use of water resources in agriculture. The lowest stream flow is in March. Water allocation between schemes numbered 5, 6, and 7 are critical because the irrigation demand in that month is peaked. Because the stream flow decreases from December to March, cropping patterns in schemes numbered 6 can start in an early November and irrigation scheme numbered 7 can start in mid or late November in order to avoid an overlapping of irrigation peak demand period.

CHAPTER 1 INTRODUCTION

This paper presents the results of the Physical Component of the Water Resources Management Research Capacity Development Programme (WRMRCDP) implemented from 2006 to second half of 2011, which is funded by the Australian Agency for International Development Programme (AusAID). Its collaborative partners are the Cambodia Development Resource Institute (CDRI), University of Sydney (USYD) and the Royal University of Phnom Penh (RUPP). The WRMRCDP consists of Physical, Economic and Governance components, implemented in three provinces in Cambodia, namely Kampong Chhnang, Pursat and Kompong Thom.

Hydrological analysis is the main focus of this component, and the case study was conducted in Stung Chrey Bak catchment in Kompong Chhnang province (Figure 1.1). Two other reports on the Physical Component research have been published as part of the CDRI Working Paper series (Chem & Someth 2011; Chann *et al.* 2011).

Figure 1.1: Location Map of Stung Chrey Bak catchment



1.1 Background

Water resources management in Cambodia relates to multiple sectors, including agriculture, water supply and sanitation, energy, industry, navigation, tourism and fisheries. The Royal Government of Cambodia considers water as a key factor to poverty reduction, economic development, food security and environmental conservation (MOWRAM 2004). People are faced with shortages of freshwater for consumption and irrigation during the dry season and the early part of the wet season[1] as well as during the dry spell within the wet season. During periods of reduced or no rainfall, irrigation infrastructure plays a crucial role in providing supplementary irrigation to rice production. However, the irrigation infrastructure is inadequate to meet current irrigation demand. Many schemes were initiated during the period 1975 to 1978 (by the Khmer Rouge Regime) and were inappropriately designed and constructed. They have become run-down, and many are in a state of disrepair. Recognising the importance of water to promoting rice production, the government has repaired many of these irrigation schemes to restore irrigation water service provision for growing dry and wet season crops.

The rehabilitation and development of irrigation infrastructure have mostly taken place with little evaluation of water availability or institutional structures to ensure the sustainable use and management of surface and groundwater resources within the catchment. There is clearly a need for better management. Effective management of water infrastructure requires balancing the requirements of all water-related sectors. Integrated Water Resources Management (IWRM) is seen as an approach that can improve sector coordination. In implementing IWRM, institutional strengthening and improved hydrological knowledge are key elements. A sub-catchment scale management unit, and a Participatory Integrated Catchment Management (PICM) process, which is a component of IWRM, are recommended for improving Cambodia's catchment-level irrigation management (Chem & Someth 2011). This scale of management has been widely adopted in many countries, especially in South Africa (German *et al.* 2006).

The basic catchment concept is that water is a flux. What happens in one part of the catchment affects people and the environment in other parts. A higher degree of development implies greater social and environmental changes. Therefore, there is a need to update hydrological information in order to support development decision making and community participation for more collective catchment governance, which involves all stakeholders (Chem & Someth 2011). The Ministry of Water Resources and Meteorology (MOWRAM) is the lead institution managing all aspects of catchment management. However, PICM requires the participation of other sectors, from national down to the community level. Government sectors that are involved in catchment management include MOWRAM, Ministries of Agriculture, Forestry and Fisheries (MAFF), Environment (MOE), Public Works and Transport (MPWT), Industry, Mines and Energy (MIME), Rural Development (MRD), Tourism (MT), as well as the Forestry Administration (FA), the Fisheries Administration (FiA), Cambodian National Mekong Commission (CNMC), Ministry of Land Management, Urban Planning and Construction (MLMUPC), provincial and district authorities and other community-based organisations operating in the catchment boundary (MOWRAM 2011).

1 This period is sometimes termed the "small-dry season" and normally occurs between July and August.

1.2 Problem Statement

Cambodia needs to promote economic growth by prioritising investment in key sectors. Its remarkable economic growth in the last decade was in the garments, construction and tourism sectors. However, the agricultural sector still holds vast untapped potential, which in 2008 accounted for 26 percent of gross domestic product (GDP) and employed 56 percent of the labour force (Tong *et al.* 2011). With its tropical climate, it still has a large area of fertile unused arable land and unskilled labour force. Agriculture plays a crucial role in improving food security and national economy because rice is the staple food and is targeted as an export commodity and more than 80 percent of the population live in rural areas and depend on largely rice-based agriculture for their livelihoods.

Rice production is dependent upon various factors including soil type, temperature, solar radiation, seeds and fertiliser use as well as appropriate farming technology. But a key determinant of rice production is water. Water availability in Cambodia is directly affected by the monsoon climate and local landscape. Across the country, 81 percent of the precipitation occurs during the wet season from May to October. The seasonal concentration of precipitation is even higher in Kompong Chhnang province, at 84 percent. Rainfall is sparse between December and February i.e. the dry season; all the water required for growing rice during this period has to be supplied through irrigation.

Poverty studies in Cambodia recommend that further irrigation development is required to improve food security, and that more investments are needed to improve water management for agriculture (Gerald *et al.* 2007). Irrigation is a priority option for enabling rice growing beyond rain-fed cultivation and avoiding rain-fed crop failure through poor supplementary irrigation. Irrigation development consists of diverse infrastructural investments, including pumping stations, reservoir dykes, diversion structures, canals and regulators, as well as technical and institutional capacity development.

Irrigation systems have been built and further rehabilitated in many catchments in Cambodia. These systems alter hydrological processes within these catchments, for example, rainfall capture and stream water diversion changes surface and groundwater flows. Irrigation system development also links communities that live in upstream and downstream parts of the catchment, forming relationships that can be understood in terms environmental services and water usage (Knox *et al.* 2001). Therefore, understanding the hydrological process in a catchment is crucial for improving sustainable and equitable irrigation development. However, capacity for hydrological analysis in reference to the catchment hydrology is limited. In water-limited conditions, water is often shared among users with competing demands, including environmental in-stream flow demands, within a catchment. The most critical issues relate to increased competition over irrigation water between upstream and downstream communities during the dry season (Chem & Someth 2011).

Almost every year, farmers in the lower part of Stung Chrey Bak catchment in Kompong Chhnang province face water shortages, flood and drought, which impose major constraints on agricultural production. Under the current arrangements, upstream irrigators have prior access to water. In order to promote sharing and more efficient use of water resources during the dry season, and for effective, equitable and sustainable water management that is socially acceptable, scientifically informed and collaborative catchment management is needed.

This research carries out a scenario-based hydrological analysis to examine the implications of different patterns of stream flow for water allocation options.

1.3 Objectives

This research sets out to examine the possibility of supporting improved catchment management through scenarios created by sound hydrological analysis that presents clear options and implications to Farmer Water User Communities (FWUCs), Commune Councils (CCs) and the Provincial Department of Water Resources (PDOWRAM), who are currently in charge of irrigation management at community and provincial levels.

1.4 Research Questions

The main questions addressed in this paper are:

- What are the implications for downstream users of different patterns of stream flow resulting from alternative patterns of irrigation water use in the Stung Chrey Bak catchment?
- How can different hydrological scenarios be presented and communicated as part of a decision-support process within a forum of catchment level water users and managers?

CHAPTER 2 THE WATER EVALUATION AND PLANNING SYSTEM

2.1 Background

Cambodia is facing formidable water management challenges, in terms of the social equity of water allocation for irrigation and the environmental quality of the catchment. Progressive policy reforms in Cambodia including river basin management are expected to bring about improvements in sustainable and equitable development. However, Cambodia needs good methods to support and inform sound decision making on water sector development.

The traditional method of supply-based water management is no longer appropriate to today's competitive water requirement conditions. A more integrated approach to water management in Cambodia has emerged through the adaptation of Integrated Water Resources Management (IWRM) in water law and policy. Theoretically, this approach places water supply projects as well as issues of water quality and ecosystem conservation in the context of demand-side water management. But translating this IWRM concept into practice remains a great challenge.

This study used the Water Evaluation and Planning model (WEAP) developed by the Stockholm Environmental Institute. WEAP is designed to incorporate the values of demand management into a practical tool for water resource planning, and places the demand side of the equation (water use patterns, equipment efficiency, re-use, price and allocation) on an equal footing with the supply side (stream-flow, groundwater, reservoir and water transfers). WEAP is a tool for examining alternative water development and management strategies. As a database, it provides a system for maintaining water demand and supply information. As a forecasting tool, it simulates water demand, supply, flows, storage, pollution generation, treatment and discharges. As a policy analysis tool, WEAP evaluates a full range of water development and management options and takes account of multiple and competing uses of water systems (Sieber & Purkey 2011).

2.2 The WEAP Model

IWRM requires a multidisciplinary approach that considers an array of physical and social aspects, because water management considered in a catchment context is often influenced by a set of linked physical, biological and socioeconomic factors, including climate, topography, land use, surface hydrology, groundwater hydrology, soil, water quality, ecosystems, demographics, institutional arrangements and infrastructure (Yates *et al.* 2005).

The physical aspect of water management requires technical tools and expertise of various stakeholders. Increased demand for directed use, such as domestic and irrigation, requires a trade-off between the uses of water for human versus economic needs. Water allocation for more than two competing users or sectors can be viewed as a further stressor. Diversion of water for irrigation provides a good agricultural service, though doing so limits the quantity of water available for other needs. Irrigation service provision incurs stresses on the natural system through changes to water quantity and quality. This process directly links to the hydrological cycle.

The WEAP model has five views: schematic, data, results, overviews and notes (van Loon & Droogers 2006). The approach for modelling includes five steps:

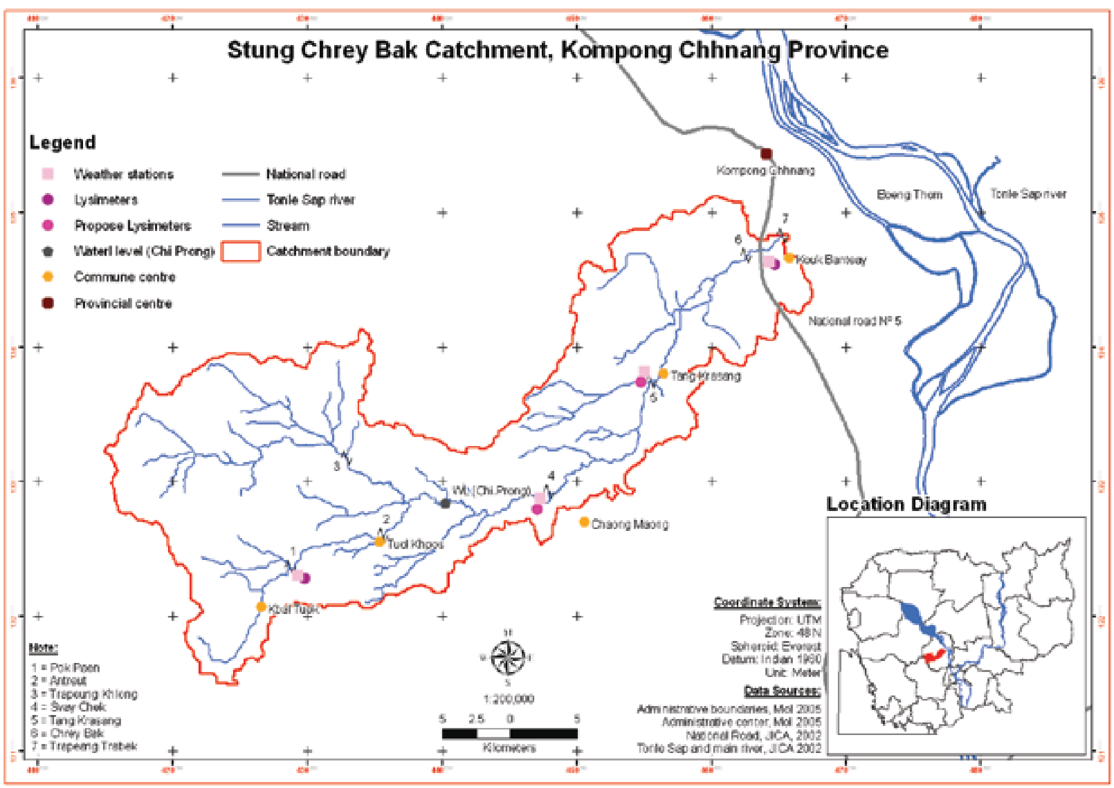
1. Creation of a geographic representation of the catchment;
2. Entering data for different supply and demand sites;
3. Comparing results with observations;
4. Defining scenarios;
5. Comparing and presenting the results of different scenarios.

Steps 1 to 3 were conducted by experts (hydrologists), while steps 4 and 5 involved exchange of ideas between stakeholders and policymakers, i.e. stakeholders participate in decision-making.

2.3 Case Study: Stung Chrey Bak Catchment

Stung Chrey Bak stream is one of the medium tributaries of the Tonle Sap River. The stream is eighty km long. It drains water from the Stung Chrey Bak catchment into the Tonle Sap River near the Boeng Thom Lake (Figure 2.1).

Figure 2.1: Hydrological Map of Stung Chrey Bak Catchment



The main stream runs across two districts, namely Tuek Phos and Rolear Biér. Local people call it by different names. From upstream to downstream it is called (1) Stung Srae Bak and (2) Stung Chaktuem and (3) Stung Chrey Bak main stream. The Stung Chaktuem connects to the Stung Chrey Bak Main Stream at Chi Prong confluence (Takab village). The main stream has a total catchment area of 663 km^2 (Figure 2.1 & Table 2.1).

The Stung Chrey Bak stream is an important tributary of the Tonle Sap River. It contributes about 288.5 million m^3 per annum to the Tonle Sap River flows. It also contributes inflows of freshwater during the dry season from November to April each year.

Table 2.1: Characteristics of Stung Chrey Bak Catchment

Catchment characteristics	**Name**	**Length (km)**	**Area (km^2)**
Main stream	Stung Chrey Bak	54.50	663
Tributary	Srae Bak	25.60	176
	Chaktuem	28.20	190
Stream flow (annual)	289 million m^3		

Table 2.2: Irrigated Area by Scheme

Scheme No.	**Name of scheme**	**Irrigation demand (m^3)**	**Irrigated area (ha)**	**Dry or wet season**	**Type of Irrigation**	**Irrigation structure**
Scheme 1	Pok Paen	5528142	621	Wet (May-Dec)	Diversion	Weir
Scheme 2	Antreut	2982170	335	Wet (May-Dec)	Diversion	Weir
Scheme 3	Trapeang Khlong	8240546	926	Wet (May-Dec) Dry (Jan-Mar)	Diversion	Weir
Scheme 4	Svay Chek	16023600	1800	Wet (May-Dec)	Diversion	Weir
Scheme 5	Tang Krasang	49975120	5620	Wet (May-Dec) Dry (Jan-Mar)	Diversion (small reservoir)	Spillway, weir
Scheme 6	Chrey Bak	3745700	455	Wet (May-Dec) Dry (Jan-Mar)	Diversion	Temporary weir
Scheme 7	Trapeang Trabek	3660000	610	Early wet (May-Jun) Dry (Nov-Mar)	Diversion	Weir
Total		90155278	10367			

Stung Chrey Bak catchment is one of the focal irrigation developments during the 1980s and 1990s, when Cambodia struggled with food insecurity after the Khmer Rouge regime was ousted (1975-1978) and due to the externally imposed economic blockade (1979-1991). About 8700 ha of wet and dry rice growing area reportedly relies on water from this catchment (Chem & Someth 2011). To date, the addition of irrigation schemes 2 and 3 to the demand analysis has increased the irrigated area of wet and dry season rice cultivation to 10,367 ha and the irrigation scheme has expanded to seven locations in the catchment, instead of the five as shown in Chem & Someth (2011) (Table 2.2).

2.4 Climate

Climate information on the catchment 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 November to April, and the rainy season from May to October. 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 records indicate a variation in mean wind speeds across the catchment, the south (Pursat) experiencing much lower winds than the north (Siem Reap) and the 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.

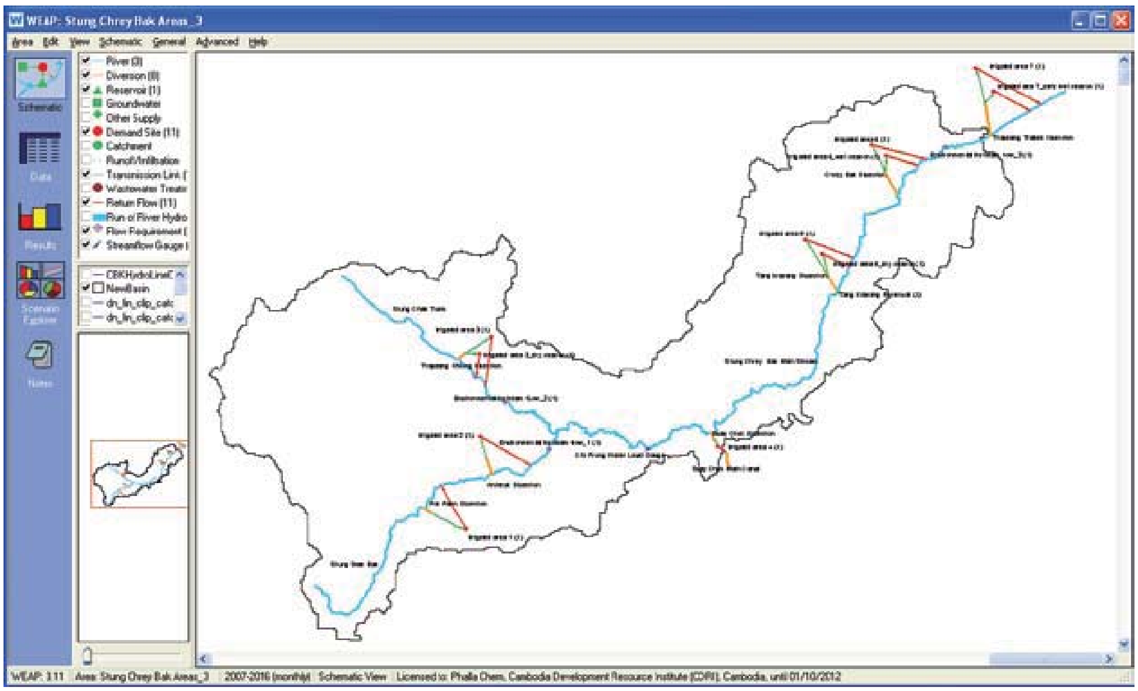
Rainfall in the catchment peaks in September–October. In July–August, a short period of drought may damage wet season crops that are not irrigated. Mean annual precipitation and evaporation are 1593 mm and 1591 mm at Phnom Penh, 1414 mm and 1344 mm at Pursat, and 1415 mm and 1625 mm at Siem Reap. Evaporation is usually highest in April.

CHAPTER 3 WEAP - STUNG CHREY BAK CATCHMENT

3.1 Schematic

A shape file was imported into WEAP from ArcGIS catchment boundary map of the Stung Chrey Bak catchment. The digital map of the catchment was derived from the 1:100,000 digital map of Cambodia. It includes physical features including drainage, catchment boundary and irrigation site locations (Figure 3.1).

Figure 3.1: Various Nodes of WEAP Stream Schematic View



3.2 Data

3.2.1 Inflow

The observed stream flows in Pok Paen and Chi Prong (Takab village) are the main inflow data used in this study. Stream discharge and water level measurements have been recorded since 2007 by the Department of Hydrology and River Works of MOWRAM in Stung Chrey Bak Main Stream at Chi Prong water level gauge station (Figures 2.1 and 3.1). Water level data (Table 3.1) were used to establish a rating equation (Figure 3.2) called the "least-square fitting technique" using a regression analysis method to extend the calculation of daily discharge from 2007-2010 (Chem & Someth 2011). The rating equation is:

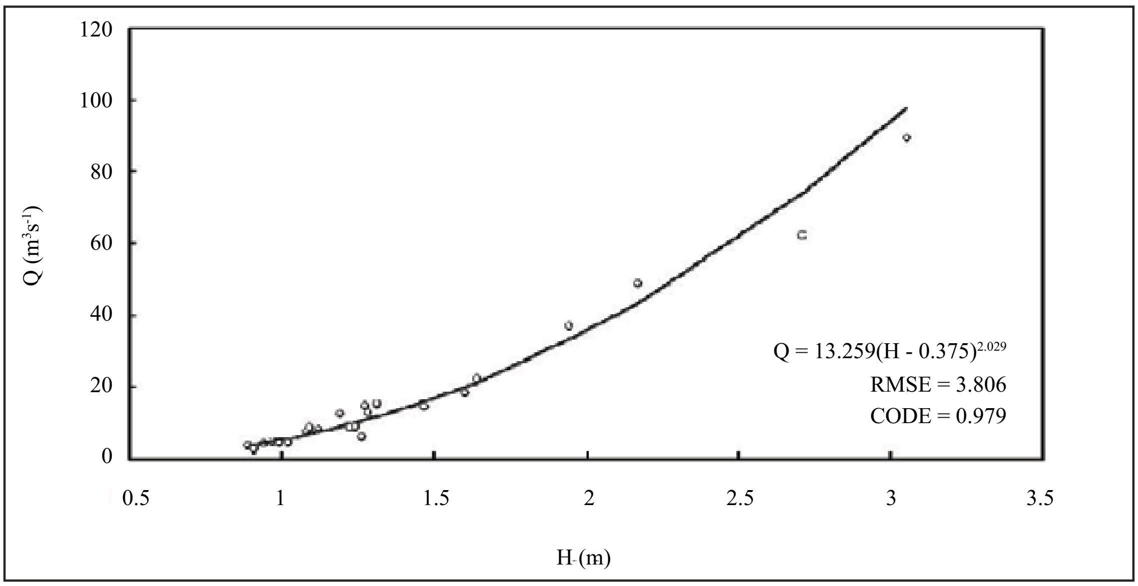
$$Q = 13.259\ (H - 0.375)^{2.029} \tag{1}$$

where, Q is discharge (m^3/s) and H is the stream water level (m).

Table 3.1: Stream Water Level Observation in Stung Chrey Bak Catchment

Observation	Name	Latitude (X)	Longitude (Y)
Gauging station 1	Pok Paen	428117	1323347
Gauging station 2	Chi Prong	440315	1328938
Gauging station 3	Svay Chek	447193	1328770
Gauging station 4	Tang Krasang	455342	1338281
Gauging station 5	Trapeang Trabek	465617	1348308
Rainfall station 1	Rolear Bier	121263	1043988
Rainfall station 2	Tuek Phos	120317	1043842
Rainfall station 3	Tang Krasang	320734	1043386

Figure 3.2: Rating Curve and Equation of Stung Chrey Bak Main Stream



Water levels in the five gauging stations shown in Table 3.1 have also been collected since 2008. The water level gauges are attached to the walls of the weirs and spillways. The daily stream water level is collected at each site by a member of the Farmer Water User Community (FWUC) and recorded in hydrological observation log-books. These water level data were used to calculate discharge through weir and spillway structures at each irrigation scheme using weir and spillway discharge formulas. Spillways are broad-crested and sluice gates are operated with sliding gates. Therefore, the discharge through a sluice gate is calculated under the orifice condition and discharge through a spillway is calculated under the broad-crested weir condition.

The formula for sluice gate discharge is $Q = C_d A\sqrt{2gh}$ (2)

where Q is discharge through the sluice gate (cubic metre per second); C_d is the discharge coefficient depending on hydraulics structure design (dimensionless); A is flow area respective to the opening gate height and flow width of the sluice structure (square metre); *g* is gravity of acceleration (metres per second square); and, *h* is height from the headwater to the centre of the opening gate height (metres) (McCuen 1989).

The formula for spillway discharge is $Q = C_d Bh^{0.5}$ (3)

where Q is discharge through the spillway (cubic metres per second); C_d is discharge coefficient depending on the shape of the spillway crest (dimensionless); B is flow width or spillway crest length (metres); and, h is flow height above the spillway crest (metres) (Garg 1999). The monthly discharges in each river reach were calculated for Stung Sre Bak, Stung Chaktuem and Stung Chrey Bak main stream and are shown in Table 3.2.

Table 3.2: Stream Flow in 2007

Month	Stung Srae Bak (million m^3)	Stung Chaktuem (million m^3)	Stung Chrey Bak main stream (million m^3)
January	5.50	3.40	8.90
February	5.10	0.50	5.60
March	1.50	2.50	4.00
April	1.40	4.40	5.80
May	4.30	17.50	21.80
June	6.40	6.50	12.90
July	9.00	13.70	22.70
August	16.10	18.10	34.20
September	14.90	41.20	56.10
October	24.40	38.70	63.00
November	2.10	34.30	46.40
December	0.80	6.30	7.10
Annual Flow	**91.00**	**197.00**	**289.00**

3.2.2 Rice Crop Growing Seasons

Wet season rice crop cultivation in Pok Paen, Antreut, Trapeang Khlong, Svay Chek and Tang Krasang irrigation schemes starts in May to June and the crop is harvested in November to December each year, depending on rainfall. Farmers normally do their first ploughing in April or May. Transplanting is done in June to July, depending on weather conditions.

Dry season rice crop cultivation in some parts of Trapeang Khlong, Tang Krasang, Chrey Bak and Trapeang Trabek irrigation schemes starts in mid-November. Most dry season rice varieties take three months to mature. Farmers who start sowing their rice seeds in mid-November can harvest in mid-February, and those who sow seeds later, i.e., January to February, can harvest in March to April.

3.2.3 Rice Crop Irrigation Requirement

In order to estimate the rice crop irrigation requirement (IR) it is essential to know the rice crop water requirement (CR). The term IR in Cambodia refers to two circumstances: first, a full irrigation in the dry season when there is no rain throughout the crop period (i.e. the duration from sowing to harvest); second, a supplementary irrigation in the wet season when there is plenty of rain to satisfy a proportion of the rice crop water requirement.

The rice crop water requirement varies throughout the crop period. The duration from the first irrigation to the last irrigation is called the base period (B). Irrigation is stopped before the harvest; therefore, the base period is shorter than the crop period. This does not complicate the practical application of irrigation planning.

Growing rice in a climate such as Cambodia's requires water to be supplied by both full and supplementary irrigation to maintain soil moisture at a level for rice to grow. In irrigation planning, it is essential to calculate CR in terms of water need height (e.g. millimetres) per hectare per crop period. Technically, CR is dependent on climate condition and the crop's stage of growth. Before knowing how much water is needed, it is essential to understand how the rice crop consumes water to grow and provide a good yield. Rice extracts water through its root system and releases water to the atmosphere through its leaf and stem systems. This process is called transpiration (T). The water stored in the rice field, in the leaves and stems of the rice plants, which is intercepted during rainfall is also lost to the atmosphere through evaporation (E). Therefore, the rice crop water requirement (CR) is the sum of transpiration and evaporation, which is termed the evapotranspiration of a crop ($_eT_c$).

The supplementary IR is the difference between the actual CR and the effective rainfall (Pe). The IR is calculated using the formula below:

$$IR = CR - Pe \qquad (4)$$

Effective rainfall during the growing period is the total amount of water used by the plant in transpiration through stem and leaf systems, and evaporation from the adjacent soil area (Garg 1999).

Considering all the factors, including evapotranspiration, water losses through soil percolation and effective rainfall, the CR for the Stung Chrey Bak was calculated. The irrigated areas by irrigation scheme and the IR in terms of irrigated height per crop period are shown in Table 3.3.

Table 3.3: Irrigation Demand

Irrigation scheme	Irrigated areas (ha)		Irrigation requirement (mm)	
	Wet season	Dry season	Wet season (6-month crop period)	Dry Season (3-month crop period)
Scheme 1	621	-	890[a]/	-
Scheme 2	335	-	890	-
Scheme 3	920	6	890	845
Scheme 4	1800	-	890	-
Scheme 5	5500	120	890	845
Scheme 6	350	105	890	600[b]/
Scheme 7	100	510	600	600
Total	9626	741		

a/ Water requirement amount is for sandy loam soil rice field;
b/ Water requirement amount is for clay soil and it is assumed that there is no rainfall to substitute the CR.

3.3 Defining Demand Management Scenarios

This section discusses three demand management scenarios: reference, 5 percent annual increase in irrigation demand, and additional reservoir storage. These three scenarios are built on the current account year in 2007. The assumptions are summarised in Table 3.4. All scenarios in this Table will be evaluated based on two options: (1) including 30 percent of monthly stream flow for environmental in-stream flow (e-flow) and (2) excluding 30 percent of monthly stream flow for e-flow.

Table 3.4: Summary of Scenario Assumptions

Demand management scenarios	"What if" questions and key assumptions
Reference	Irrigation demand will be reduced by 1 percent if the physical infrastructure and management skills of irrigation operators are improved. Command area is kept at 10,367 ha.
Annual increase in irrigation demand	Irrigation demand will be reduced by 1 percent if the physical infrastructure and management skills of irrigation operators are improved. Annual increase in irrigation demand of 5 percent from 2008 to 2016 is assumed. Irrigated area increases to 16,083 ha.
Additional reservoir storage	Irrigation demand increases 5 percent annually from 2008 to 2016. Irrigation infrastructure and management are improved. Irrigated area increases to 16,083 ha.

3.3.1 Current Account Year and Time Steps

The current account in 2007 is a presentation of the current water system; in this case it represents the Stung Chrey Bak catchment in Cambodia. It is to calibrate the data and assumptions which accurately reflect the actual operation of the catchment system. It consists of the definition of supply and demand data; e.g. the definition of river, reservoir and withdrawal nodes, etc. This current account irrigation demand does not take e-flow into account. After evaluation and comparing the results from WEAP for the three scenarios, the best option for recommendations for future water resources management and catchment planning can be chosen.

The scenarios are modelled and evaluated starting from 1 January in the current account year 2007 to 31 December 2016. There are 12 time steps per year (based on the calendar months). The WEAP-Stung Chrey Bak year 2007 and time steps are shown in Table 3.5.

Table 3.5: Year 2007 and Time Steps

#	Title	Abbreviation	Length (days)	Begins	Ends
1	January	Jan	31	1 Jan	31 Jan
2	February	Feb	28	1 Feb	28 Feb
3	March	Mar	31	1 Mar	31 Mar
4	April	Apr	30	1 Apr	30 Apr
5	May	May	31	1 May	31 May
6	June	Jun	30	1 Jun	30 Jun
7	July	Jul	31	1 Jul	31 Jul
8	August	Aug	31	1 Aug	31 Aug
9	September	Sep	30	1 Sep	30 Sep
10	October	Oct	31	1 Oct	31 Oct
11	November	Nov	30	1 Nov	30 Nov
12	December	Dec	31	1 Dec	31 Dec

3.3.2 The Reference Scenario

The reference scenario is built on the current account year in 2007 to answer the "what if?" question for predicting a situation for the study timeframe from 2008 to 2016. This scenario evaluates a question of with and/or without considering e-flow, does the reported 10,367 ha of the rice growing area have enough irrigation water?

First, the reference scenario assumes that if budget is invested to improve physical infrastructure (i.e. to construct an irrigation canal and regulator) and managerial skills (i.e. operation and maintenance, agricultural extension and water allocation training), irrigation water will be used more effectively. Through many discussions with farmers and the experiences of low irrigation efficiency in Cambodia due to low quality infrastructure and technology and limited capacity of irrigation operators, it is assumed that the improvement programme will reduce irrigation demand by one percent[2] over the analysis timeframe from 2008 to 2016.

Second, the reference scenario will evaluate the reported irrigated area against the stream flow and environmental condition of the catchment to see if it has sufficient water in two circumstances: with and without considering e-flow. Two other questions can be asked in this scenario: If there is enough water for 10,367 ha, is there any possibility of further increasing the irrigated area? And if there is not enough water, what is the best demand option given the potential supply from the catchment?

3.3.3 The Annual Increase in Irrigation Demand Scenario

The annual increase in irrigation demand scenario tries to answer the "what if" question in a catchment planning exercise. Dry season irrigated areas in the catchments around the Tonle Sap Lake have greatly increased: some entail expansion onto new land and others involve double rice-cropping on the same plots of land. The dry season irrigated area in Stung Chrey Bak catchment had increased up to 741 ha in 2007 from less than 100 ha in 1992, equivalent to a 6 percent annual increase. However, calculating future possible demand should not just be

2 There is no exact justification for this. The assumption is made based on discussion with and the operating skills of FWUC members.

based on the potential expansion of the irrigated area, but should also consider the availability of water in a catchment. Therefore, this scenario assumes the irrigated area will increase by 5 percent per year over the period from 2008 to 2016.

The scenario evaluates the implications of increased irrigation demand against the water availability and e-flow of a catchment. The assumption that the improvement programme will reduce the irrigation demand by one percent over the analysis timeframe from 2008 to 2016, as stated in the reference scenario, is also applied in this scenario.

3.3.4 The Additional Reservoir Storage Scenario

The additional reservoir storage scenario is considered when the stream discharge is low. Only irrigation scheme number 5 has some reservoir storage capacity, whereas the other six irrigation schemes do not and can only divert water from the main stream into the main canals. The additional reservoir storage scenario is set to evaluate how unmet demand would be improved if the reservoir storage is added to the supply.

This scenario assumes that (1) the improvement programme will reduce irrigation demand by 1 percent over the analysis timeframe from 2008 to 2016, and (2) the irrigated area will increase by 5 percent per year to 2016, and asks the question: What if the reservoir storage in irrigation scheme number 5 is added to the supply source?

CHAPTER 4 RESULTS AND DISCUSSION

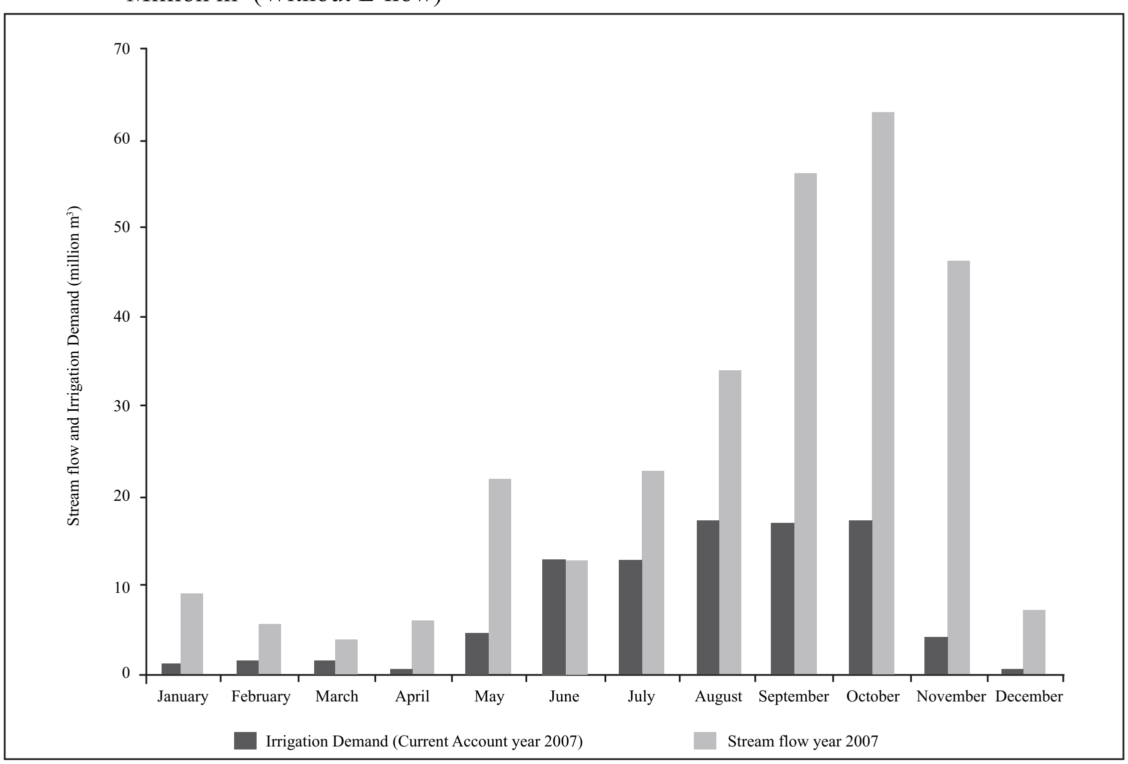
4.1 Current Account Irrigation Demand Simulation

Irrigation water demand in the current account is calculated based on the reported area of 10,367 ha. This calculation does not take e-flow into account because it has never been considered prior to this study. The monthly variation in irrigation water demand was estimated based on the rice crop factor and the pattern of farmers' rice crop cultivation.

Table 4.1: Irrigation Demand by Scheme in 2007

Irrigated area	Irrigation demand (m^3)
Scheme 1	5528142
Scheme 2	2982170
Scheme 3	8189840
Scheme 3 (dry season)	50706
Scheme 4	16023600
Scheme 5	48961000
Scheme 5 (dry season)	1014120
Scheme 6	630000
Scheme 6 (wet season)	3115700
Scheme 7	3060000
Scheme 7 (early wet season)	600000
Total	**90155278**

Figure 4.1: Comparison of Monthly Stream Flow and Current Account Monthly Irrigation Demand in Million m^3 (Without E-flow)



The current account simulation found that irrigation demand is 90.16 million m³ per annum. There is no unmet demand; however, the demand in June is very close to supply. This means that if there is no improvement programme in the future and if the command area is increased and/or the e-flow is included, there will be water shortages in June. Irrigation demand by irrigation scheme is shown in Table 4.1 and a comparison of monthly stream flows and monthly average irrigation demand is shown in Figure 4.1.

4.2 Environmental In-Stream Flow (E-flow)

Water withdrawal from the stream during both wet and dry seasons was considered. Thirty percent of the annual stream flow is assumed to be the minimum e-flow demand for sustaining the stream's ecosystems. Irrigation demand in the dry season is high from December to March, and in the wet season it is high from June to October.

The e-flow has never been considered prior to this study. Therefore, this model exercise is an attempt to raise a few options for policymakers and key stakeholders (i.e. FWUC members, CCs, district and PDOWRAM officials) to decide whether to consider e-flow and for them to be informed to be able to weigh the balance between irrigation demand and the e-flow demands i.e. which one and when should it be secondary or primary priority (based on their political, economic and environmental considerations). This study does not try to make any decision on the e-flow. The monthly e-flow demand for 2008-2016 is shown in Table 4.2.

Table 4.2: Monthly Environmental In-stream Flow (E-flow) Demand (million m³)

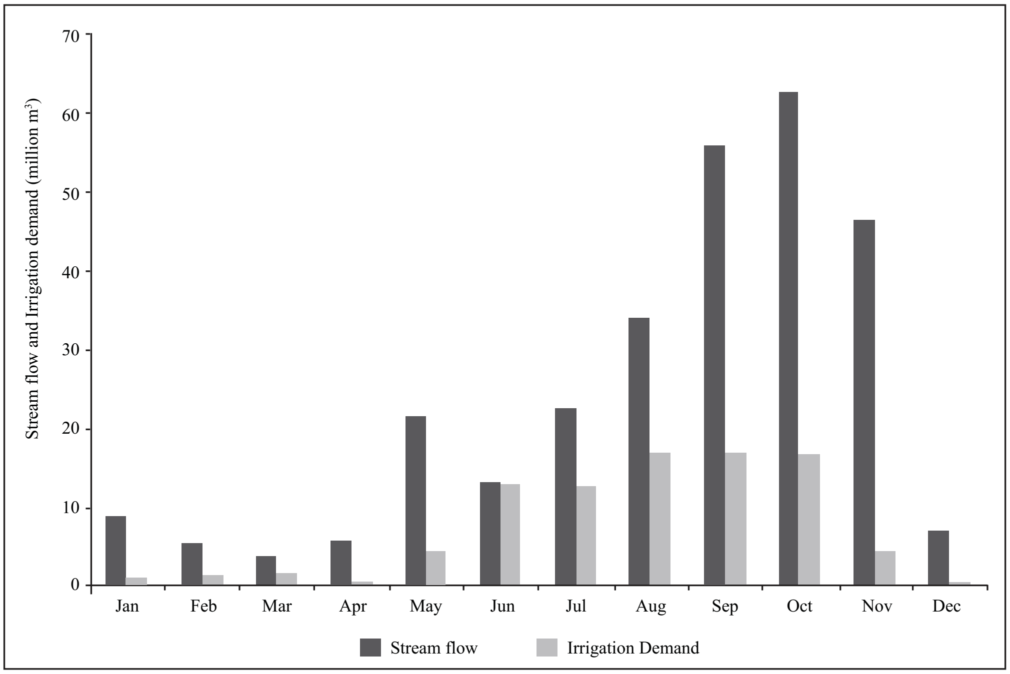
Stream	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Stung Srae Bak	1.16	1.05	1.16	1.12	1.16	1.12	1.16	1.16	1.12	1.16	1.12	1.16
Stung Chaktuem	1.16	1.05	1.16	1.12	1.16	1.12	1.16	1.16	1.12	1.16	1.12	1.16
Stung Chrey Bak Main Stream	1.16	1.05	1.16	1.12	1.16	1.12	1.16	1.16	1.12	1.16	1.12	1.16
Total	**3.47**	**3.14**	**3.47**	**3.36**	**3.47**	**3.36**	**3.47**	**3.47**	**3.36**	**3.47**	**3.36**	**3.47**

4.3 Reference Scenario Simulation

The reference scenario calculates irrigation demand in 2007 at 89.35 million m³ per annum. This irrigation is less than the current account because it takes into account the 1 percent reduction in demand by implementing infrastructure and operational improvement programmes as assumed in Section 3.3.2. Excluding the e-flow, this simulation shows that there is no unmet demand (Figure 4.2).

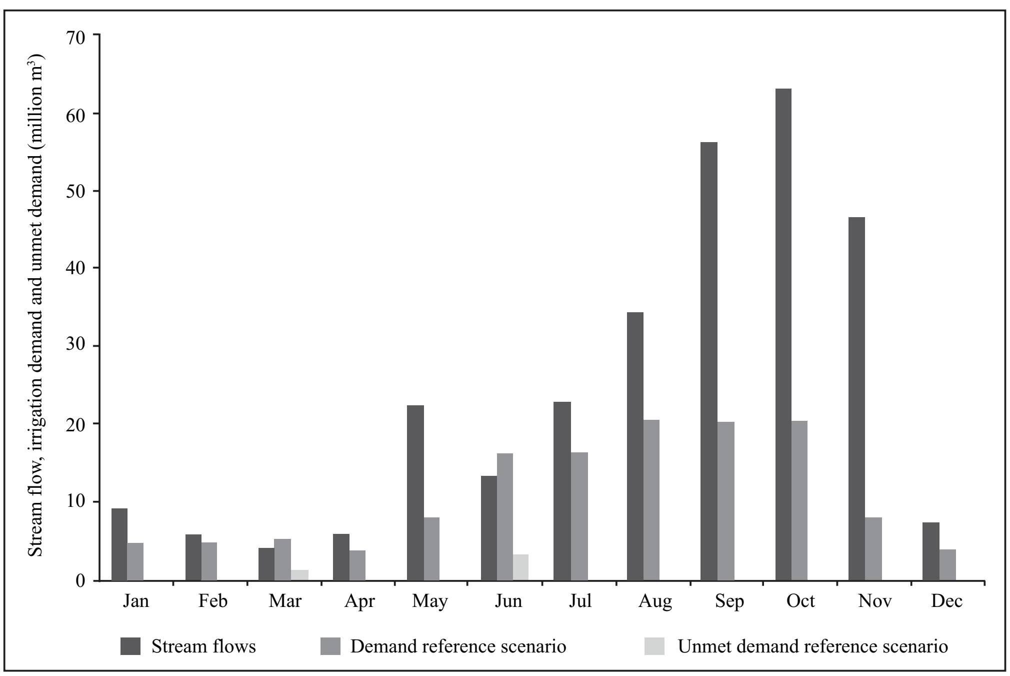
The first conclusion of this scenario evaluation is that without considering the e-flow demand, the rice growing area of 10,367 ha, 741 ha in the dry season, has enough irrigation water (Figure 4.2). This seems to contradict the actual problems reported by farmers. Farmers who grow dry season rice in irrigation schemes 6 and 7 (Figure 2.1) constantly raised the issue of water shortages. It can be concluded that the current problem is not just caused by physical water shortage, but also by lack of proper irrigation infrastructure and poor management for delivering irrigation services efficiently to the farmers, and the past lack of coordination in water allocation between upstream and downstream FWUCs. During the last three years (2009-2011), irrigation water allocation seems to have been better when the FWUCs in both upstream and downstream areas actively participated and helped coordinate water allocation between schemes 5, 6 and 7.

Figure 4.2: Supply-demand relationships in reference scenario when environmental in-stream flow (e-flow) is set to second priority



The second conclusion is that, including e-flow demand, a given rice growing area of 10,367 ha would face unmet demand of 4.2 million m³ mostly in June and only 0.95 million m³ in March (Figure 4.3).

Figure 4.3: Supply-demand relationships in reference scenario when e-flow is set to primary priority



4.4 The Annual Increase in Irrigation Demand Scenario

The annual increase in irrigation demand scenario evaluates the question of what if the irrigated area is annually increased by 5 percent per year from 2008 to 2016. The projected-irrigation area in 2016 is 16,082 ha (Figure 4.4); the projected monthly average irrigation demand is shown in Table 4.3.

Table 4.3: Monthly Irrigation Demand in million m^3 – 5 percent Annual Increase in Irrigation Demand Scenario

Irrigated areas	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Area 1	0	0	0	0	0.34	1.03	1.03	1.38	1.38	1.38	0.34	0	6.89
Area 2	0	0	0	0	0.19	0.56	0.56	0.74	0.74	0.74	0.19	0	3.72
Area 3	0	0	0	0	0.51	1.53	1.53	2.04	2.04	2.04	0.51	0	10.21
Area 3 (dry season)	0.02	0.02	0.02	0	0	0	0	0	0	0	0	0	0.06
Area 4	0	0	0	0	1.00	3.00	3.00	3.99	3.99	3.99	1.00	0	19.97
Area 5	0	0	0	0	3.05	9.15	9.15	12.20	12.20	12.20	3.05	0	61.02
Area 5 (dry season)	0.32	0.44	0.44	0.06	0	0	0	0	0	0	0	0	1.26
Area 6	0.20	0.24	0.24	0.04	0	0	0	0	0	0	0.02	0.06	0.79
Area 6 (wet season)	0	0	0	0	0.19	0.58	0.58	0.78	0.78	0.78	0.19	0	3.88
Area 7	0.95	1.14	1.14	0.19	0	0	0	0	0	0	0.08	0.31	3.81
Area 7 (early wet season)	0	0	0	0.11	0.26	0.26	0.11	0	0	0	0	0	0.75
Total	**1.48**	**1.84**	**1.84**	**0.41**	**5.55**	**16.1**	**15.9**	**21.1**	**21.1**	**21.1**	**5.4**	**0.4**	**112.4**

The average annual irrigation demand is 112.36 million m^3. Two implications for catchment planning in this scenario can be discussed.

First, without considering e-flow demand and climate variability, the unmet demand is 2.97 million m^3, mainly in June. Second, including e-flow demand, unmet demand would increase to 7.89 million m^3 , mainly in June (in March, is 1.3 million m^3) (Figure 4.5). This scenario evaluation concludes that the water supply from the catchment is not sufficient for irrigating 16,083 ha. The irrigated area should be limited to 10,000 ha when e-flow is primary priority. On the other hand, the irrigated area could be expanded up to 12,000 ha when e-flow demand is set to secondary priority if infrastructural and managerial improvement programmes are implemented.

Figure 4.4: Projected Irrigated Area for 5 percent Annual Increase in Irrigation Demand Scenario (ha)

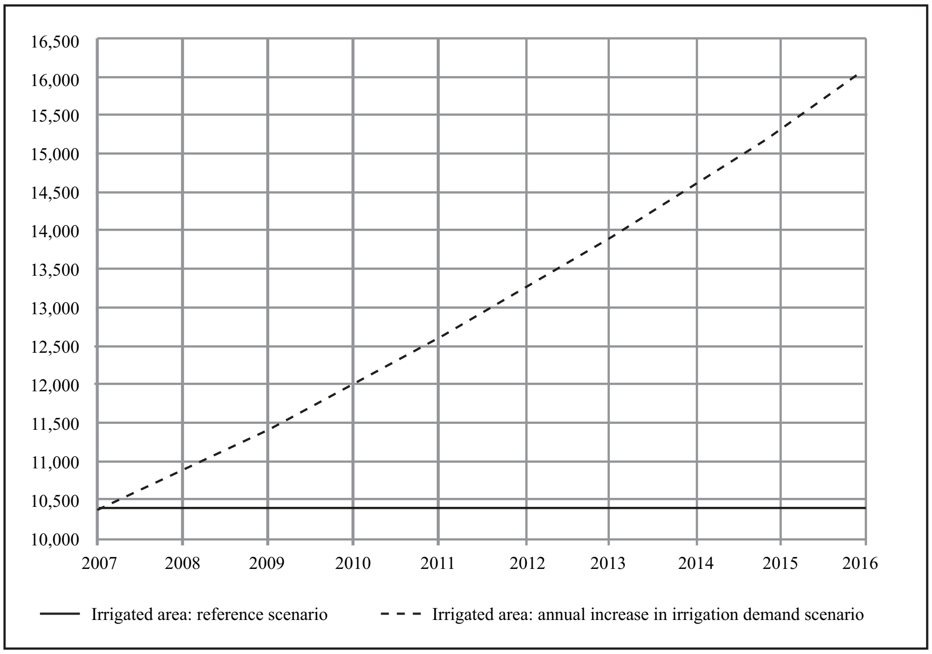
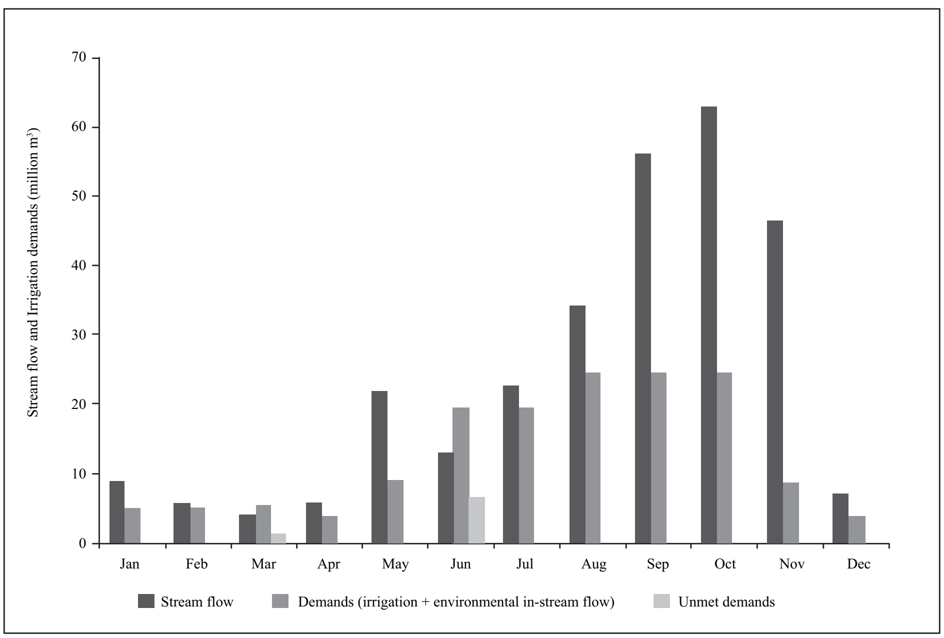


Figure 4.5: Monthly Stream Flow-demand-unmet Demand Relationships – 5 percent Annual Increase in Irrigation Command Scenario (million m^3)



4.5 The Additional Reservoir Storage Scenario

Without considering e-flow demand, the simulation of additional reservoir storage scenario for 2008-2016 found unmet demand of 2.97 million m^3 mostly in June. This is because the existing reservoir storage capacity of irrigation scheme numbered 5 is very small compared to demand, and its storage has no significant impact on augmenting water availability for a critical period.

CHAPTER 5 CONCLUSION AND RECOMMENDATION

This study attempts to apply the WEAP model to evaluate different irrigation demand management scenarios, including reference, 5 percent annual increase in irrigation demand and additional reservoir storage, to address problems of water allocation in the Stung Chrey Bak catchment.

Annual stream flow was calculated as 289 million m^3. Stream flow varies from wet to dry season. A five month (December, January, February, March and April) total low stream flow was about 31.4 million m^3. This study concludes that this water supply in the catchment is enough to grow 742 ha of dry season rice. This dry season irrigated area cannot be increased further when taking into account the e-flow and other water use sectors such as domestic, livestock and small rural industrial consumptions, which are not included in this study. Any further increase in the command area will incur serious water shortage.

In addition, the dry season water demand and supply results seem to contradict actual problems reported by farmers. There are some water shortages in the dry season, especially in irrigation schemes numbered 6 and 7. It can be concluded that the current problem is not just caused by physical water shortage, but also by the lack of proper irrigation infrastructure and irrigation scheme management (operation and maintenance) for delivering irrigation services efficiently from upstream to downstream (from irrigation scheme numbered 5 to 6 and then to 7) communities, and lack of good coordination between upstream and downstream FWUCs in their water allocation decision-making. This confirms the need for taking into account other factors such as irrigation system, climatic conditions, land use/cover, water allocation, water release, and other governance and social factors while interpreting this result.

On the other hand, the lowest stream flow in the wet season is in June, at about 12.9 million m^3 followed by July with about 22.7 million m^3. Irrigation demand for 9,626 ha in the wet season started rising in June to its peak in August-October. Because reservoir storage is small, unmet demand in June is significant.

There is no unmet demand for the reference scenario when e-flow demand was set to second priority in the analysis. However, unmet demand increased to 4.2 million m^3 when e-flow demand was included.

The 5 percent annual increase in irrigation demand scenario concludes that the irrigated area could have reached 16,083 ha by 2016. Without considering e-flow, unmet demand would be 2.97 million m^3. This unmet demand would increase to 7.89 million m^3, mainly in June and March, when e-flow is included.

There is no major reservoir in the Stung Chrey Bak catchment. In irrigation scheme numbered 5, the reservoir has no significant impact on improving unmet demand. Geographically, building larger reservoirs in this catchment is not a feasible option.

Three patterns of stream flows were observed: dry season (November-April), wet season 1 (May-July: low flow) and wet season 2 (August-October: high flow). The variations of stream flow have implicated greatly on farming and ecosystem; i.e. low stream flow in March and June limits farmers from increasing their irrigating areas, and it causes environment degradation. By way of recommendation, taking into account e-flow demand and other in-stream uses, the irrigated area in Stung Chrey Bak catchment should be limited to 10,000 ha. Alternatively, when considering e-flow as a secondary priority, the irrigated area should not be expanded beyond 12,000 ha and only in tandem with a programme to improve irrigation infrastructure and governance.

In a situation of water limitation, a harmonising crop planning between upstream and downstream cropping areas, bases on stream flow patterns, is crucial in optimising the use of water resources in agriculture. The lowest stream flow is in March. Water allocation between schemes numbered 5, 6, and 7 are critical because the irrigation demand in that month is peaked. Because the stream flow decreases from December to March, cropping patterns in schemes numbered 6 can start in an early November and irrigation scheme numbered 7 can start in mid or late November in order to avoid an overlapping of irrigation peak demand period.

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