A Framework for Improving the Management of Irrigation Schemes in Vietnam

Proceedings of a workshop held in Ho Chi Minh City, Vietnam, 28 November 2003

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Foreword

Vietnam's future food security depends on the country's ability to expand agricultural production. This, in turn, will rely heavily on increased efficiency of irrigation systems. About 80% of the country's four million hectares of cultivated paddy and upland crops are equipped with some form of irrigation.

This publication contains the main findings of a project carried out in Vietnam which focused on the operation and management of publicly managed irrigation systems. These findings formed the basis for the development of a management improvement model for irrigation systems in Vietnam which is also applicable to other systems throughout Asia.

The papers were presented at a workshop held at the Southern Institute for Water Resources Research in Ho Chi Minh City, Vietnam in November 2003.

We are pleased to publish these proceedings and hope that the book will be a valuable resource for irrigation managers and policy makers to formulate and implement strategies for improving the planning and operation of water resource and irrigation systems.

Peter Core
Director
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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
BCM	billion cubic metres
CV	coefficient of variation
DGPS	differential global positioning system
ETo	evapotranspiration
FAO	Food and Agricultural Organization of the United Nations
GUI	graphical user interface
GIS	geographical information system
HCMC	Ho Chi Minh City
HPC	hand-held personal computer
IMC	irrigation management company
IMSOP	irrigation main system operation (computer model)
MCM	million cubic metres
RIS	relative irrigation supply
RRD	Red River Delta
RWS	relative water supply
SA	summer–autumn
SR	supply ratio
US$	United States dollar
VND	Vietnamese Dong
VIWRR	Vietnam Institute for Water Resources Research
WS	winter–spring

A Framework for Improving the Management of Irrigation Schemes in Vietnam: an Overview

Hector M. Malano,* Biju A. George* and Brian Davidson†

Introduction

When many irrigation schemes are planned and built, how much thought is put into how they should be managed? What can happen is that what can be termed an 'adoption approach' is taken, where a method of control is chosen from a scheme in operation elsewhere in the country or in some other country. It would appear that using this approach has resulted in the management of irrigation schemes not evolving extensively. The advantage of this approach is that the risks of institutional failure are minimised. The use of this approach is understandable, as the operation of a scheme is complex, occurs at many levels and involves many different fields of expertise (including hydrology, economics and institutional analysis). However, adopting a method of operating an irrigation scheme from another country or era may not be the best approach to the problem. Even if an ideal approach is initially chosen, things change while habits become entrenched. A legitimate question that could be asked is: Is the current method of operating an irrigation scheme ideal?

There are two, related elements to this question. First, and simply, what is considered to be ideal? Does this mean that, given the existing physical infrastructure, the scheme running at maximal efficiency? Or does it mean that the returns to users are maximised, given the cost of operation. Or does it mean that it is financially sustainable, without putting undue costs on society or the environment.

Second, given the complexity of an irrigation scheme, surely a number of different fields need to be investigated. To fix a problem in one geographic area may very well cause problems elsewhere in the scheme. Further, fixing an engineering problem may lead to financial or institutional problems.

It would appear that the question of ideal operation should be resolved in a holistic manner, accounting for different geographic locations, and incorporating different fields of expertise. In other words, the engineering, economic, social and institutional issues need to be addressed on a wide scale if any changes to the operation of an irrigation scheme are considered. Further, the degree of change needs to be assessed using a variety of measures. Improvements, or reductions, associated with any change can then be assessed using the tools associated with each field or discipline.

There are two problems associated with taking a holistic approach to assess the problems of operating irrigation schemes. The first is philosophical. Karl Popper (quoted in James 1980) puts a succinct case against holistic approaches. He argues that a holistic approach is so complex that policy makers are not provided with the directions needed to make change. In essence, Popper presents a case for marginalism, which is an anathema to holism. The second objection is that such an approach means that an 'ideal' operational plan cannot be achieved. What is derived is a set of trade-offs where gains in one area are measured against costs in others.

The purpose of these proceedings is to outline an approach for assessing the operation of an irrigation scheme using a holistic approach. To illustrate how this works, examples are drawn from irrigation schemes in Vietnam. The papers presented in this volume were discussed at an ACIAR workshop in Ho Chi Minh City in November 2003.

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An Outline of the Problems

An irrigation scheme is that physical structure that moves water in time and space. The crucial element required of an irrigation scheme is the need to regulate water flows. Consequently, some method of storing, moving and distributing water is required before it can be called an irrigation scheme. It is usually a large item of infrastructure, incorporating sometimes a dam, channels, sluice gates, levee banks, pumps etc. It can be as small as a bucket and a pipe, but it cannot be a bucket or a pipe on its own. By moving water in time and space, the things produced from water can also be moved in time and space. For instance, the spatial proliferation of cotton and rice production in Australia has occurred because of the availability of inexpensive and reliable supplies of water. In Vietnam, where water is regulated temporally, two and in some cases three rice crops are grown each year, whereas once only one crop could be grown.

It would be easy to confine an analysis of the management and operation of an irrigation scheme to what one sees in terms of a physical structure. However, given the definition presented above, such an approach would appear to be a little narrow. As an irrigation scheme runs for a purpose, any analysis of it must to some extent be measured in terms of how well it performs the things it is suppose to do. Clearly, its ability to deliver water effectively and efficiently is the key criterion upon which the operation and management can be gauged.

However, what does effective and efficient water delivery mean? From the definition presented above it must mean more that an assessment of the flow of water. Perhaps the best way of assessing an irrigation scheme is to segment the areas of concern according to the flow of water which, in turn, tracks the effects it has. While such an approach is logical, it is perhaps better to isolate the problems that can occur along this flow. From this base, the major area of concern (hydrological, economic and/or institutional) can be isolated and a method of analysis identified (see Figure 1). Key indicators, the measures of effective and efficient water delivery, are the outputs of such an approach and can be used for comparative purposes.

Taking this approach, one can start with an assessment of the flow, distribution and volume of water passing through an irrigation scheme. These problems, which are basically hydrological, can be assessed by conducting a 'systems analysis'. This involves the identification of the system
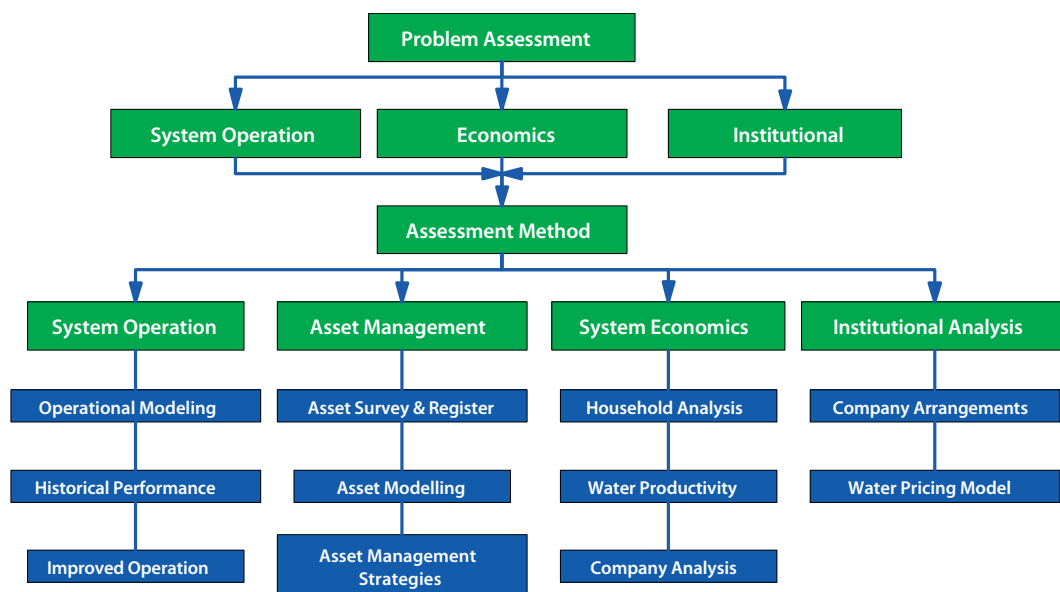

Figure 1. Main components of the research project

components and physical linkages and the relationships that describe the operation of the water supply system. The main measure arising from this analysis is the volume of water in total, or on an area or time basis. They are the most important indicators of any analysis of irrigation schemes, especially given the definition of moving water in time and space. But such physical measures are not sufficient to understand all the elements that affect system operation.

There other elements surrounding the physical water operation of the system that must be considered. It could be asked how effectively the asset is used. This can be evaluated by looking at the maintenance and renewal of assets. The key indicators are how much is spent on maintaining and renewing the infrastructure for shifting water, or how often the structures break down. At another level, it could be asked: is the agency that manages the flow of water economically viable and does it work efficiently? To assess these two issues requires an analysis of the agencies financial standing and its management structures. In addition, because many irrigation agencies are public entities, a wider view of their governance needs to be investigated. In other words, the rules governments impose on these agencies that they own and the management arrangements imposed on farmers can have a profound impact on their effectiveness.

An analysis of the flow of water and the agency that delivers it is, by itself, insufficient, especially given the definition of an irrigation scheme presented above. One also needs to assess the impacts the regulation of water has on users, the economy and the environment. A gross margins analysis can be conducted to assess the effects water has on farmers in particular and users in general. Such an analysis indicates the returns a producer receives from changing the flow of water.

If one wants to go further, regional and environmental impacts can be assessed using a variety of techniques, from input–output analysis for regional impacts to environmental impact statements for an analysis of natural phenomena. However, a social benefit–cost approach can, in a limited way, be used to accomplish both these tasks. In this study, these further issues are not discussed. Many of them are beyond the control of those who operate irrigation schemes, the people at whom this volume is directed. In summary, a number of tasks need to be undertaken if an irrigation scheme is to be assessed and its operation improved. These tasks involve a combination of hydrological, economic and institutional analysis tools. What is being proposed is an assessment of the effectiveness and efficiency of delivering water to where it is needed. In essence, the question can be resolved by calculating the quantity of water flowing through a scheme at a given price. To successfully do this requires an analysis of the system, the assets at hand, the viability and management of the controlling agency and the impacts on users. Once done, the price of water to different participants and the returns therefrom can be assessed.

The Approach

In the research described in this volume, a system approach is taken to identify the main technical, economic and social constraints that preclude operators of irrigation systems from achieving a higher level of performance. Examples of how to assess these constraints and to diminish their impacts are taken from irrigation schemes in Vietnam. Figure 1 presents a summary of the problems, together with the main components of the research project. It also reflects the order of presentation in these proceedings.

The research program was structured along four main thematic strands:
• system operation
• asset management
• system economics
• institutional analysis.

While the presentation of the results is structured along these lines of research, each component involves several complex operations individually, a process that results in a high level of interconnectedness between the individual elements.

Main System Operation Modelling

The main function of the irrigation system is to deliver water to satisfy well-defined service provision objectives of flexibility, reliability and adequacy. Vietnamese systems often fall short in one or more of these attributes, depending on the location-specific conditions of the system. An 'Irrigation Main System OPeration' (IMSOP) model was developed to simulate a variety of system configurations, and was provided with adaptive capacity to incorporate the more salient features of irrigation systems in Vietnam.

This component of the research focuses on the use of computer modelling to:

- assess of the historical performance of irrigation systems
- simulate and analyse alternative operational regimes to enhance system performance
- assist in the day-to-day operation of the system for scheduling and computing flows to meet irrigation demand.

The adaptive nature of the modeling approach used in IMSOP was used to evaluate and improve the operational performance of three irrigation systems: at La Khe and Dan Hoai in Hatai Province near Hanoi; and at Cu Chi in the vicinity of Ho Chi Minh City. Each of these systems has specific features that required individual adaptation of the model. The La Khe and Dan Hoai irrigation systems feature high levels of energy input for irrigation supply and disposal of excess rainfall during the rainy season. The Cu Chi irrigation system is a gravity-fed system within the Dong Nai Basin that faces increasing intersectoral competition. More water is demanded for urban and industrial users in Ho Chi Minh City. In addition, river flows must be increased to avoid saltwater intrusion.

Once each system was modelled, it was possible to simulate alternative operational scenarios. These were used to demonstrate to irrigation agencies and other stakeholders a selection of operating procedures that could be implemented in the future. These selected scenarios were then field-tested to evaluate their comparative advantages and disadvantages, and their ability to deliver the desired quantity of water. The preferred option was then adopted by the irrigation company on the basis of the supply:demand ratio to each of the main service areas within the system, equity of supply across the system and simplicity of operation. The process of adaptation and change in operating rules was achieved in consultation with the key stakeholders in the project, notably the irrigation management companies (hereinafter the IMCs) and the water users.

Managing the Infrastructure

A country's ability to meet the future food-supply challenges may depend largely on improvements to irrigation infrastructure. Many irrigation schemes, like those in the Red River Delta (hereinafter the RRD) of Vietnam, rely heavily on pumping for irri-

gation and drainage and many operators are concerned about the high energy costs of the operation. Of great concern is the lack of sustainability of the irrigation infrastructure due to the inability to sufficiently invest in operation and maintenance. At present, there are no provisions for linking the cost of operating the irrigation and drainage infrastructure to the actual price charged for these services. This, coupled with the inability of government to subsidise these services at an appropriate level, places severe constraints in the ability of IMCs to sustain their operations.

The delivery of irrigation and drainage service requires a hydraulic infrastructure that is designed, operated, maintained and upgraded in the most cost-effective manner to meet the desired service objectives (Malano et al. 1999).

What managers of irrigation schemes need to focus on is the development of a comprehensive framework for the implementation of an asset-management program for the IMCs. This system will allow the IMCs to plan their long-term strategy for the creation of new assets, the rehabilitation of assets to their original design specifications or the modernisation of assets to meet new service requirements. Hofwegen and Malano (1997) define asset management programs as 'A plan for creation or acquisition, maintenance, operation, replacement, modernization and disposal of irrigation and drainage assets to provide agreed level of service in the most cost effective and sustainable manner'. Currently, the price of irrigation delivery service charged by the IMCs in many countries, including Vietnam, bears no relation to the infrastructure and operation and management costs. A key factor in optimising the outcomes from this decision-making process is the ability to make informed choices from a number of alternative future asset scenarios. The tools developed in this project enable the IMCs to put in place a transparent process to ascertain the actual cost of service provision, and in particular the actual cost associated with alternative infrastructure strategies.

The asset-management modelling framework has three main components:

- a database of assets detailing geographical locations of assets, design features, maintenance records and asset condition and performance
- an analysis module that enables the modelling of future asset strategies, including the calculation of future liabilities and life-cycle asset costs

- a set of alternative strategies for the long-term management of the asset infrastructure.

The asset database enables asset operators to maintain an up-to-date register of the existing assets. A geographical information system (GIS) asset-management software program called 'Asset Manager[©]' was developed to facilitate the rapid recording, update, retrieval and manipulation of the existing asset base. The software has been tested and fully implemented in the Cu Chi and Dan Hoai irrigation systems. The software was used to evaluate several strategic options available to the IMCs to invest, maintain and modernise their asset base. The economic assessment of these options provided the key component for the calculation of the actual cost of supplying water for irrigation in these systems and, by extension, a key element for designing a water pricing model for these systems.

Financial Viability of Water Supply Companies

There is a belief that the performance of many publicly owned IMCs is poor. For instance, Turral and Malano (2002) argue that technical improvements could be made in the delivery of water to many schemes in Vietnam, leading to greater efficiency. Chien (2001) and Anh et al. (2003) allude to the problems of managing irrigation schemes in Vietnam and the lack of farmer empowerment when dealing with these companies. To study the economic performance of irrigation, three interrelated aspects need to be examined:
- the financial viability of the IMCs
- the performance of the land and water resource systems
- the economic performance of the farming enterprises served by these IMCs.

While the other aspects need (and will be) dealt with, the first of these issues—the financial viability of IMCs—is arguably the most important, as there is abundant evidence that these companies face huge difficulties in maintaining and renewing their assets. One of the most-often cited claims for the problems associated with running these IMCs is their apparent reliance on government subsidies to survive.

There is a need to provide a framework to analyse the financial viability of these companies by looking at their cost structure and its relationship to the price of the water supply and drainage service. The metrics used in this analysis consist of 18 performance measures: six revenue measures and two expenditure measures disaggregated into ten sub-measures and eight financial performance measures. These metrics are the result of financial quantities expressed on an area basis, a volume basis or as dimensionless quantities.

The framework was applied to the current company operation in the Cu Chi irrigation system. The outcomes of the analysis provided an insight into the financial difficulties faced by these companies and, more importantly, it provided an opportunity to test the methodology, which can be applied to other systems in Vietnam and elsewhere.

The analysis highlighted some critical aspects of the companies' operations.
- The IMCs (of which Cu Chi is typical) are heavily reliant on government subsidies to carry out their operations.
- The level of government subsidies is insufficient to ensure the long-term sustainability of IMC assets.
- The level of expenditure on maintenance is consistently below the standard needed to prevent the rapid decay of the company assets.

Land and Water Productivity

Murray-Rust and Snellen (1993) argued that the performance of any irrigation system depends in part on the efficiency with which the irrigation system uses resources in providing these services. This 'resource-use performance' evaluates the return from agriculture produced from water resources. The common indicator of resource-use efficiency is the crop yield, either per unit of land or per unit volume of water. To illustrate the resource-use efficiency, field experiments were conducted in a branch canal of the Cu Chi system from 2000 to 2003 to estimate water-use efficiency and productivity by quantifying the water balance components. The results of the analysis revealed very low output of rice per unit volume of water. It was also found that there is a tendency to diversify from rice to upland crops, like maize and peanuts, which are more profitable especially during the winter–spring season. In summary, far too much water is used in the case under investigation.

The Economic Performance of Farmers

Attempts to improve the efficiency of publicly managed irrigation schemes are undertaken within a framework that most suggested improvements will benefit the users of water, i.e. farmers. Thus, it is necessary to investigate the effects that the supply of irrigation water has on farmers. What is important from this analysis is the approach that was taken. It is necessary to survey a selected number farms in each scheme. Then, a whole-farm budget for each farm is constructed. These data are supplemented with local knowledge on farm and household activities and circumstances. From this base, it was possible to investigate the economic impacts water has on each household. By comparing households along a canal, down the irrigation scheme, certain conclusions can be drawn about the impacts of different water availability. However, it should be kept in mind that, since each farm is, in reality, a separate entity, managed differently and possibly for a different purpose, strict comparisons between farms may not be possible. To illustrate the technique, a gross margins analysis was undertaken of representative farms in the Cu Chi, La Khe and Dan Hoai irrigation schemes. The aim was to assess whether farm profitability was affected by variability in the supply of irrigation water due to each farm's location within the system, and the cost of that water. It was found that the nature of the farming system is defined by the provision of irrigation, yet the prices paid for water and variability in its provision would appear to have little impact on crop yields and farm incomes in two of the three schemes. In the third scheme (at Cu Chi), crop yields and net returns from cropping per hectare appear to be considerably less in farms located at the end of the irrigation system.

Institutional Analysis and Water Pricing

It has been argued that volumetric pricing for water would improve the efficiency of irrigation water delivery over the area-based pricing system currently in place in many countries around the world. However, many of the arguments put forward in favour of volumetric charging ignore the institutional reforms and infrastructural adjustments that would be required to implement such a change. There is a need to suggest a process by which a volumetric charge, albeit a partial one, could be implemented in a system which has area-based charges. One way of doing this is to introduce water users associations that would evolve over time to represent the farmers who live along a single canal. These associations could buy and pay for water from a water-supply company on a volumetric basis, and distribute it to farmers who pay for it on an area basis.

In Vietnam, the communes or cooperatives currently buy the water. Along any canal there can be up to six different communities buying water. This leads to problems associated with spatial location and maintenance of the canal. A single water users association representing all users along a canal may prove to be a beneficial institutional change. Using the example of the La Khe irrigation scheme in Vietnam, it was found that farmers had the potential to reduce the amount they spent on water. However, existing institutional arrangements prevent these reforms from being undertaken.

Description of Study Area

Any assessment of an irrigation scheme requires some knowledge of the farming system within which it operates. The farming system is dependent on the irrigation scheme and vice versa. In this study, three irrigation schemes are assessed in order to illustrate the concepts that are enunciated. Two of the schemes are in the north of Vietnam, while the other is in the south (see Figure 2). This section presents details of the region under investigation, concentrating on the irrigation schemes in question.

Vietnanese agriculture

Vietnam is a long, narrow country with a land area of approximately 330 million km^2. It stretches from 8 to 22°N and has a coastline of nearly 3500 km. Such north–south elongation, coupled with great differences in topography along a long coastline, results in a great diversity in climate. For instance, tropical monsoon conditions predominate in the south, and rice is grown along river deltas, while in the north a cooler monsoon climate exists. Tree crops are grown in higher areas in the north, while rice prevails in lower regions. This diversity results in different farming systems in different

regions. In total, 17% of the country is arable, of which 3.3 million ha is irrigated (Chien 2001). Irrigation schemes exist in both the north and the south. Vietnam has a population of over 80 million and a labour force of over 38 million people, of whom 67% are involved in agriculture. Agriculture accounts for 26% percent of the country's GDP (BTR 2003). In Vietnam, agriculture relies heavily on irrigation for water supply in the dry season and for the removal of flood waters in the rainy season.

The cropping year in the north of Vietnam can be divided into three distinct periods. Spring is a dry season that is dependent on irrigation to sustain crops. The season starts in early March and continues to the end of June. The major crop is rice. Other crops, such as vegetables, potatoes, sweet potatoes, maize and peanuts are also grown. The summer season is dependent on monsoon rains. It starts in early July and finishes at the end of October. Rice is the main crop produced. The winter season is from the middle of November to the middle of February. No rice is produced during the winter, yet farmers will produce what are termed 'dry crops' (maize, vegetables, soybean, potatoes, etc.). Winter is a period when virtually no irrigation occurs in the north of Vietnam.

The farming system in the south also has three growing periods, but they differ from those in the north. The distinct growing periods are called the 'winter–spring' (December–March), 'summer–autumn' (April–July) and the 'main' (August–November) seasons. Rice is the principal crop in the
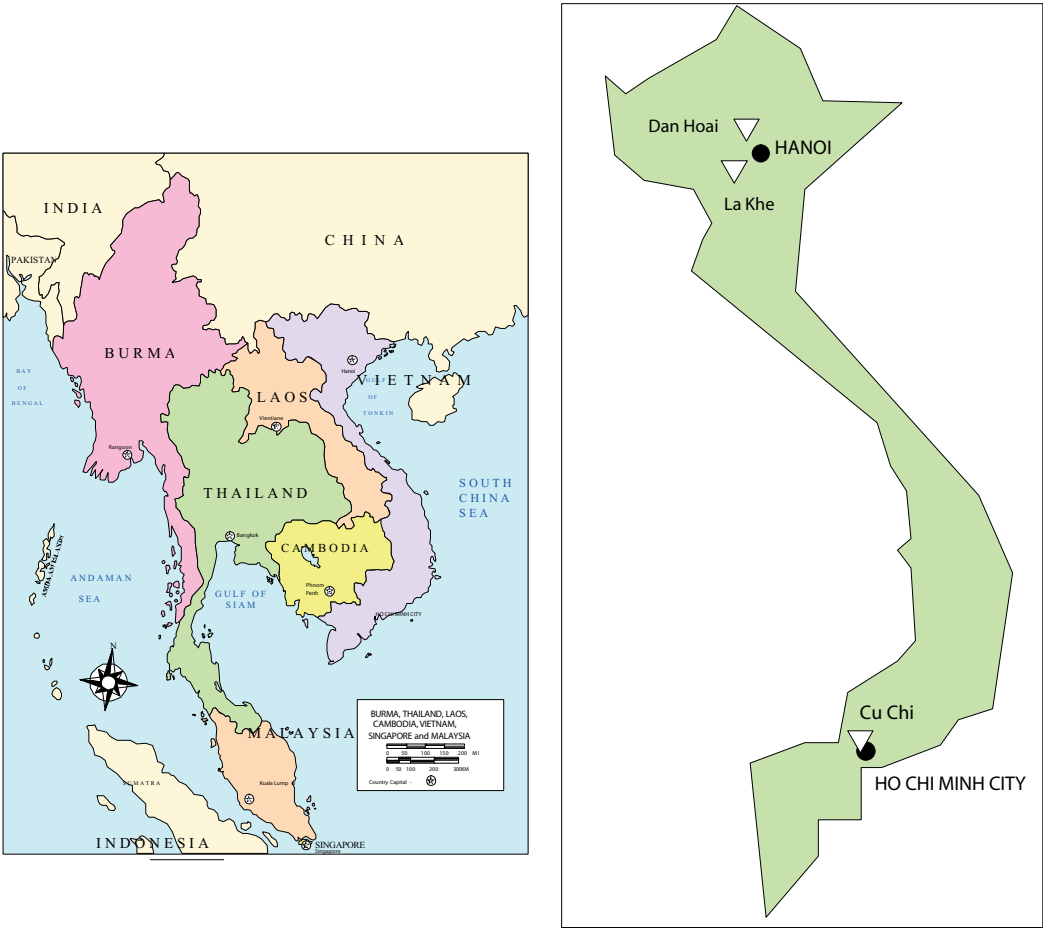

Figure 2. Location of selected irrigation systems

summer–autumn and main (or monsoon) seasons. During this latter season either short-growing rice or the more traditional long-growing varieties can be planted. As in the north, a variety of crops other than rice can be grown during the dry season.

The role agriculture and irrigation play in Vietnam is little different to that played in many other countries. Irrigated agriculture in Vietnam is heavily concentrated in the RRD, the Mekong Delta and the Saigon River System. The RRD supports nearly half the country's rice production. Irrigation systems in the RRD rely heavily on pumping (80% of 850,000 ha) for the provision of irrigation and drainage services. This is achieved by some 1700 pumping stations and more than 7500 pump units.

The performance of these systems is disappointing. The high energy cost required to operate them is a cause of great concern to their operators and managers. This, coupled with a shortfall in irrigation revenues, has created severe constraints for the sustainability of the irrigation infrastructure. While the ecological and agricultural characteristics of the Mekong Delta and Saigon River system differ from the RRD, they share common problems related to the sustainability and water management practices within the irrigation systems.

Rice accounts for the bulk of the irrigation area and water use in the country. In recent years, since the achievement of rice self-sufficiency, dryland crops such as maize, peanuts, potatoes and vegetables are becoming increasingly popular because of their higher economic value. However, there is a growing competition for water among different users in the country, due to the increasing adoption of a cropping pattern that comprises three crops per year in the majority of the irrigation schemes, and the growing demand for water from metropolitan areas as a result of rapid urban and industrial growth. Thus, agriculture's share of water is likely to decline in the near future. In addition, further crop diversification and increases in productivity require a more efficient delivery of irrigation and drainage services.

The Cu Chi system

The Dau Tieng reservoir system is the largest in the Dong Nai basin. The reservoir has an effective live storage of 1.1 BCM and a maximum surface area of 27,000 ha. The system is used to regulate the Saigon River, and supplies water to 170,000 ha of agricultural land. The reservoir also supplies limited amounts of domestic water to Tay Ninh Province and Ho Chi Minh City, and provides flood control protection to the riparian area. Reservoir releases are also used to regulate saline water intrusion in the low-lying reaches of the Saigon and Vam Co Dong rivers.

The Cu Chi irrigation system is located in the East Branch Canal of Dau Tieng Reservoir in Tay Ninh Province. The system was constructed with the aim of supplying irrigation to 12 communes covering 12,000 ha in the northern part of the Cu Chi district. To date only 8500 ha have been irrigated. The main canal is 11 km long, with a design discharge of 14 m^3/s. The system's infrastructure consists of more than 1500 concrete structures. Canal N31-A was constructed in 1993 to expand the irrigated area by 2500 ha. Due to lack of flow-regulating structures in the main supply canal, the current operational rules are designed to provide a constant supply at the diversion point of the Cu Chi system, leading to potential inefficiencies when rainfall occurs.

The soils are predominantly light, with parts of the district affected by waterlogging and salinisation as a result of large seepage losses associated with rice irrigation. The area receives an average annual rainfall of 1861 mm of which 90% occurs in the rainy season. The remaining seasons are dry, with irregular light showers only. The low rainfall during the dry season makes irrigation indispensable for the cultivation of crops. Rice is the principal crop in the two main seasons: summer–autumn and main crop. During the winter–spring season, farmers grow peanuts and maize in addition to rice. Unlike the cultivation of rice, the area planted with winter crops varies significantly from year to year.

The Dan Hoai system

The Dan Hoai system is located 25 km from Hanoi. The main canal is 23.5 km long and has three cross-regulators to control water levels. In Dan Hoai, 15 km of the 23.5 km long main channel have been rehabilitated and lined recently. The scheme supplies water to some 8000 ha of agricultural land where rice is the principal crop. There are two main water intakes into Dan Hoai's main irrigation channel: the Dan Hoai pumping station and the Ba Giang intake sluice. The Dan Hoai pumping station has been in use since 1962 and the Ba Giang sluice became operational in 1993. The lowest design

water level at the intake basin is +3.05 m and the highest at the channel headwork is +9.00 m. The pumping station in Dan Hoai consists of five low head pumps giving a nominal discharge of 10 m³/s.

The Ba Giang intake sluice was designed for an upstream water level of +12.70 m and a downstream water level at +8.90 m, giving a design discharge of 12 m³/s. If the water level in the Red River (at the intake basin) is higher than +10.70 m, the pumping station is shut down even if there is a need for irrigation supply. The Ba Giang culvert is opened from mainly June to September during the summer crop when the water level in the Red River at this culvert is above 8.9 m. Normally, the pumping station does not operate during this season. If the water level in the river is very low, the pumping station is operated simultaneously to meet the gap in supply.

The La Khe system

The La Khe irrigation system is located 25 km south of Hanoi on a spur channel between two rivers: the Nhue River, which acts as a bulk supply channel from the Red River, and the Da River, which acts as a drain. In the system, 5600 ha are irrigated by gravity from the main channel fed by the main pumping station, and a further 3000 ha are irrigated by secondary pumping stations that take water directly from the Nhue River. The scheme was built in 1962 to provide drainage to 13,000 ha, allow a spring rice crop to be grown under irrigation (March–June) and supply supplemental water in the rainy season (July–October). The main canal is 23 km long and has four cross regulators to control water levels. The La Khe model consists of 135 nodes including 1 pump, 116 offtakes, 14 measuring points and 4 regulators.

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Modelling and Monitoring of System Operation: Three Different Irrigation Systems in Vietnam

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Abstract

In this paper, the development of a process to diagnose and improve current operational performance of an irrigation scheme is discussed. To illustrate the technique, three different irrigation systems in Vietnam are assessed. The process involves a survey of existing infrastructure, calibration of irrigation-control structures, implementation of the operation computer model IMSOP, monitoring the existing operation, retrospective analysis of the system performance, simulation of alternative operational scenarios, then the field trial of selected scenarios chosen through a consultative process with the irrigation management companies and users. Detailed case studies in the three different irrigation systems are described.

Introduction – the Need for Assessing Performance

Large investment in irrigation infrastructure has not met the planners' expectations in Vietnam and other countries. This realisation has forced policy makers and researchers to focus on improving the irrigation system performance at different levels. Lack of financial resources and infrastructure are the major obstacles to improving the performance of the system through physical development. A logical alternative is to improve the systems operation and management through better operational procedures

and improved service delivery. Critical elements to achieve the goal of improved water management are an efficient operation of the main delivery system and effective maintenance of irrigation and drainage infrastructure (Schultz and Wrachien 2002).

In the past decade, irrigation researchers have developed and applied computer tools to plan, schedule and monitor the operation of irrigation systems to improve their performance. Simple canal operation models are useful in generating irrigation demand based on evapotranspiration estimates and a realistic description of the delivery system and its characteristics (Turral et al. 2002). Researchers have shown the capability of simple models for generating water demands at system level (George et al. 2002).

In this study, the computer model IMSOP (Irrigation Main System OPeration) was adapted for application to three irrigation systems in Vietnam: the Cu Chi System in southern Vietnam and the Dan Hoai and La Khe systems in the Red River Delta in the north of the country. This adaptive approach involved the modelling of the hydraulic and crop water demand processes

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involved in the operation of the irrigation delivery system. This paper presents a description of the IMSOP model and the modelling and field trial and implementation of improved operational rules in these systems. The results of the improved operation are compared with monitoring data obtained during the implementation process.

A Description of the Irrigation Main System Operation Model

A series of processes is involved in modelling and monitoring an irrigation scheme. These include:
- collection and collation of all available data on the system
- rating of key hydraulic control structures and flow monitoring
- computer simulation using the IMSOP model and retrospective analysis of the operational performance
- simulation of alternative operational scenarios including rotational supply
- field trial of different operational scenarios.

The IMSOP model is a steady-state hydraulic model (Figure 1) that simulates the operation of the main and secondary canals in an irrigation system (Vlotman and Malano 1987; George et al. 2004). The IMSOP model has three sub-models, which are combined to estimate crop evapotranspiration (ETo), the irrigation requirement, system operation and performance analysis by comparing the simulated results with monitoring data. The model is based on a graphical user interface (GUI) built on Visual Basic 6. The GUI is mouse-driven, with pop-up windows, pull-down menus and button controls. The different components are described below.

Evapotranspiration models

An accurate estimation of ETo is essential for developing accurate irrigation schedules. ETo is a function of climatic conditions and can be estimated in several ways, each depending on the availability of climatic data. However, the performance of different ETo estimation methods varies. The two most commonly used and internationally accepted methods are included in the IMSOP model. The
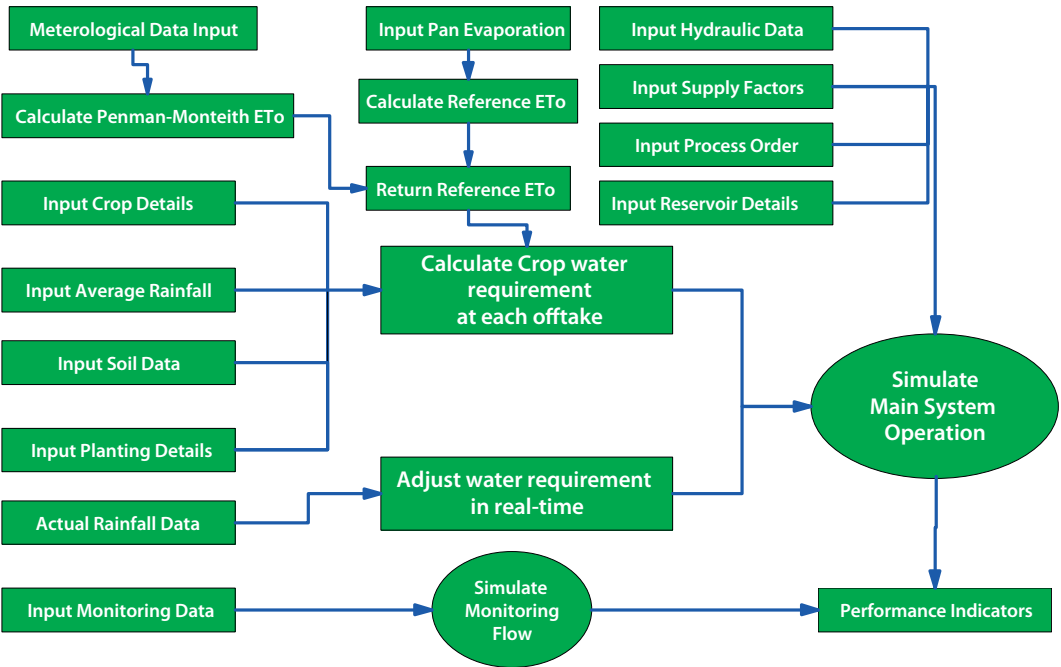

Figure 1.   Schematic diagram of the irrigation main system operation (IMSOP) model

methods included are the FAO-56 Penman–Monteith method (Allen et al. 1998) and the FAO-24 pan evaporation method (Doorenbos and Pruitt 1977). A user can select the Penman–Monteith or Pan Evaporation method according to the data available.

Irrigation requirements

Rice is the major crop grown in most of the irrigation schemes in Vietnam. It has high water demand, and the process of cultivation and irrigation differs from the practices of other field crops. The model treats the calculation of an irrigation requirement of rice and other dryland crops differently.

Crop water requirements are calculated for each offtake in the system, based on:

- knowledge of the crop type
- cropped area and time of planting
- crop growth stage
- dominant soil characteristics
- an estimate of field efficiency.

The irrigation requirement is then calculated as the sum of crop water demand, less any effective rainfall, plus land soaking, land preparation requirements and deep percolation. It is expressed as follows:

$$I_{i,j} = [ETa_{i,j} + DP_{i,j} + LSR_{i,j} +$$

$$LPR_{i,j} - RF_{eff_{i,j}}] \left[\frac{1}{\eta_j} \right] \qquad (1)$$

where

I = irrigation requirement (mm)

η = irrigation application efficiency (%)

ETa = actual evapotranspiration (mm)

DP = deep percolation (mm)

LSR = land soaking requirement (mm)

LPR = land preparation requirement (mm)

RF_{eff} = effective rainfall (mm)

i = time index

j = location index.

Actual evapotranspiration in equation (1) depends on the reference crop ETo and crop growth stage, and is estimated as follows:

$$ETa_i = ETo_i \times Kc_i \qquad (2)$$

where

ETo = grass reference crop evapotranspiration (mm/day) calculated using the FAO-56 Penman–Monteith or the FAO-24 pan evaporation method

Kc = dimensionless crop coefficient which is a function of the crop type and the growth stage.

In saturated conditions, such as those that occur in a rice paddy, water percolates below the root zone in proportion to the saturated hydraulic conductivity of the soil and ponding depth. The calculation of rice water requirements includes deep-percolation requirements, which are usually categorised by soil texture or obtained from field measurements. Furthermore, before transplanting the rice crop into the field, substantial irrigation water is required for land preparation and soaking. The depth of water required for these purposes is required as an input into the model.

Effective rainfall is that which infiltrates into the soil and is available for crop use. Effective rainfall is difficult to estimate because the infiltration rate changes with time and soil conditions, and because of the spatial and temporal variability of rain. In the current model, effective rain can be calculated by using either the fixed-percentage or variable percentage of rainfall method.

In the fixed percentage method, effective rainfall is calculated as:

$$RF_{eff_i} = 0.67(R_i - 6) \qquad (3)$$

where R = weekly rainfall (mm).

The above equation works between upper and lower bounds so that:

$$if \ R_i > 75 \ then \ RF_{eff_i} = 75 \ and \ if \ R < 10 \ then \ RF_{eff} = 0$$

In the variable percentage method, weekly rainfalls are factored as follows:

$$RF_{eff_i} = 0 \ ; \ if \ R_i \le 10 \qquad (4)$$

$$RF_{eff_i} = 0.8 \times R_i \ ; \ if \ 10 < R_i \le 30 \qquad (5)$$

$$RF_{eff_i} = (0.87 - 0.00235R) \times R_i \ ; \ if \ 30 < R_i \le 200 \qquad (6)$$

$$RF_{eff_i} = 0.4 \times R_i \ ; \ if \ R_i > 200 \qquad (7)$$

System characterisation and operation

The implementation of the model requires the description of the irrigation system in the form of a network diagram that shows all reaches of the main canal and secondary canals, hydraulic structures and offtakes to secondary or tertiary level farm units. All other inflow and outflow points, reservoirs and pumping stations can be described as nodes in the network diagram. A full longitudinal and cross-sectional survey of the canal needs to be carried out.

After calculating the water demand at defined offtakes, flows are accumulated starting at the downstream end of the system towards the headworks. They include all seepage losses, return flows, direct inflows to channel network from adjacent catchments, and deliveries to municipal and industrial water users. IMSOP determines steady, uniform flow demand in the channel network on the basis of accumulated offtake demands, and calculates the expected flows in each reach of the canal. At each structure, the model determines steady-state flow depths and calculates the operating settings for regulators and average hours of pump operation according to selected rules.

Performance indicators

The most important feature of IMSOP is that it includes a monitoring module that enables the comparison of actual supply and required demand. These can be used to calculate performance indicators of operation and management. The model uses supply:demand ratio as the indicator which is the ratio of flow supplied to the demand calculated by the model. The model calculates the indicators at each monitoring point and for the entire system.

Model application

The IMSOP model can be used in three ways (Turral et al. 2002) to:

- assess historical performance of the irrigation system, comparing simulated water demand with monitoring data
- simulate and analyse alternative operational scenarios to enhance system performance
- assist system operation in near real-time.

Data collection

The data collection for the application of the model must be carried out in the early years of the project. A flow and water-level monitoring program needs to be introduced to provide managers with routine information and to allow IMSOP's predictions to be compared with actual operation data.

Agricultural data

Crop information must be collected on a seasonal basis by interviewing farmers to determine the proportion of different crops planted in each offtake and the planting dates of each crop. An automatic weather station can be used to collect climate data for the calculation of reference crop evapotranspiration. Crop coefficients at different growth stages to convert reference ETo to actual evapotranspiration can be collected from lysimeter experiments carried out at each site. Rainfall data are required to analyse historical operation of the system and can be collected from nearby weather stations. Soil information is needed for all major soil types in the study area. Seepage tests need to be carried out using double-tube permeameters.

Calibration of key monitoring structures

The implementation of IMSOP requires a full survey of hydraulic facilities and rating of key irrigation-control structures. All significant offtakes, regulators and monitoring points need to be calibrated, together with a head, discharge and gate opening relationship for each structure. The performance of the pumps can be measured by conducting discharge and power-consumption measurements.

Flow monitoring

Manual flow monitoring was initiated at the start of the project by installing automatic capacitance water-level recorders at all monitoring points to get the most reliable and continuous record of flow depths. Routine flow monitoring can be carried out as follows:

- recording of pumping hours to estimate total supply volumes
- flow measurement at head and cross regulators in the main canal and large secondary canals, by monitoring upstream and downstream water levels, gate openings and duration of flow through these structures.

Application of the Model

ACIAR Project No. 9834 was undertaken in three different irrigation systems in Vietnam, two in the RRD and one in the Saigon River delta. Details of these schemes are given in the previous paper. The main aims of this project were to assess the current operational performance and develop improved operational procedures for the irrigation supply system. The rest of this paper describes the development of a process for analysing the performance of irrigation systems and investigating operational options that would enable a better provision of irrigation water service and enhance the productivity of the water delivered.

Case study 1 – the Cu Chi system

IMSOP modelling

The IMSOP model relies on the schematic of the irrigation system in the form of a network diagram that incorporates all reaches of the main canal, secondary canals, offtakes and all hydraulic structures on those canals. The schematic of the Cu Chi model (Figure 2) includes main, sub-main and secondary canals. Individual tertiary canals are represented as canal offtakes. This point also represents the division of management responsibility between the Cu Chi IMC and water users. The IMC is responsible for the operation, management and maintenance of earthworks and structures on the main canal and secondary canals. Farmers and farmer groups are responsible for the operation, management and maintenance of earthworks and structures from the tertiary canals to the field canals. The Cu Chi model comprises 46 nodes: 5 confluence nodes, 3 monitoring points, 3 supply nodes, 16 cross regulators and 19 offtakes.

In Cu-Chi the whole system is divided into 19 service areas, which are used as the basic units for monitoring and assessment of water balance. For the purpose of monitoring, all offtakes within a
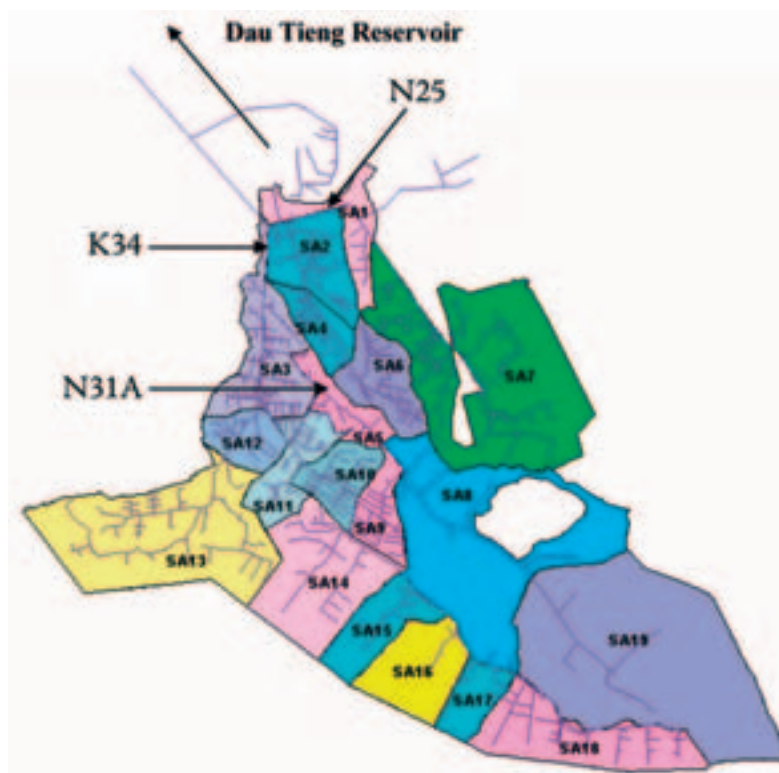

Figure 2. Schematic diagram of Cu Chi irrigation system, Vietnam

service area have been combined into a synthetic offtake for each service area. The water balance is estimated for each service area by calculating the difference between inflows into the area and out-flows leaving the area.

Analysis of past operation

The first stage of the operational improvement process consisted of a retrospective modelling analysis of the system to assess its operational performance. In this process, the seasonal irrigation demand of the system was estimated using IMSOP for all three crop-ping seasons during 2001 and for the winter–spring season in 2002. It was compared with flow-monitoring data to understand the shortcomings of the existing operation.

During the winter–spring season of 2002, supply exceeded demand by between 3% and 95% in all the service areas. A comparison was made for 14 of the 19 service areas; monitoring data were not available for the remaining 5. Supply was more than twice the demand in nine service areas and in some cases it was 3–5 times the required amount (service areas 5, 10, 12, 14 and 19). The average supply during the season was 10.5 m^3/s, which resulted in an over-supply for the entire season estimated as 62 MCM. The supply:demand ratio was found to vary from 1.03 to 5.9 across the system (Table 1).

Weekly average irrigation requirements were esti-mated for each service area and were also compared with the actual supply for all the three seasons in 2001. During the winter–spring season, the supply exceeded demand in all service areas, except 4, 14 and 18. The average supply:demand ratio for the entire area was estimated at 1.68. During the summer–autumn season, water was oversupplied to all service areas except for 3 and 4, and the average supply:demand ratio for the entire system was esti-mated at 1.89. In contrast, the amount of water sup-plied to service area 3 could meet only 46% of the demand. The supply was less than the demand in four service areas (2, 4, 12 and 14) during the main crop-ping season (the monsoon). The average supply:demand ratio for the entire system was esti-mated at 1.72 for this season. The excess water sup-plied during the whole year was estimated at 119.5 MCM. These disparate deviations between supply and demand indicate that system operation is carried out without consideration to crop water demand and proper canal regulation aimed at achieving supply objectives and equity of distribution.

Table 1. Supply:demand ratio for water, and its variation in different seasons, in the Cu Chi irrigation system, Vietnam

Service area	Supply:demand ratio			
	Winter–summer 2001	Summer–autumn 2001	Main–monsoon 2001	Winter–summer 2002
1	1.52	1.15	1.23	1.31
2	2.80	1.58	0.53	2.15
3	2.61	0.46	1.04	1.03
4	0.82	0.67	0.94	2.16
5	3.42	3.63	4.70	5.98
6	1.21	1.03	1.16	1.47
7	1.93	2.98	2.67	1.56
8	1.17	1.14	1.09	1.04
9	1.59	1.51	1.80	2.05
10	1.28	1.09	1.54	3.15
11	1.78	4.63	3.64	1.59
12	1.54	1.36	0.82	3.48
14	0.96	3.84	0.79	3.73
18	0.87	1.28	2.12	–
19	–	–	–	4.43
Average	1.68	1.89	1.72	2.51
Coefficient of variation	0.43	0.65	0.66	0.57

Modelling of alternative operational scenarios

The analysis of the system operation in Cu Chi shows that oversupply occurs in all service areas and that the amount of oversupply varies widely across the system. The irrigation company could improve the control of the supplies to service areas to achieve the goal of reducing overall consumption and improving supply equity among service areas. These objectives, however, can be achieved only by changing the existing operational rules. These pri-orities guided the selection of simulation scenarios using IMSOP. These simulation scenarios included rotational supply, in addition to the current contin-uous supply to the entire system. In rotational water supply, the water can be delivered to the system in separate blocks, allowing parts of the system to be shut-down, thus simplifying the operation and achieving better system regulation with the existing hydraulic control (George et al. 2004).

Project staff held extensive discussions with IMC staff and other stakeholders, including farmer groups, about the various options for changing the operation of the system in order to improve performance. The capacity constraints of the main canal to meet the peak water requirement during land soaking restricted the use of long-term rotational options. Moreover, fish farms located in different parts of the system restricted the length of off-time in any part of the system under a rotational supply arrangement. As a result, three different scenarios were selected, simulated by IMSOP and field evaluated. The selected scenarios were:

• continuous flow irrigation
• irrigating 2-block on 4-day rotation
• irrigating 2-block on 7-day rotation.

In order to simulate the second and third scenarios, the whole system was divided into two zones: Zone I consisting of service areas 1, 2, 4, 6 and 7 and Zone II of service areas 3, 5, 8, 9, 10, 11, 12, 13 14, 15, 16, 17, 18 and 19. Zones I and II are 2413 and 4692 ha, respectively.

Continuous flow. Irrigation requirements were simulated for all 19 service areas together with the flow required at each regulator based on the average weather and crop conditions for the winter–spring season 2003. Gate openings at each cross regulator were then determined by using the previously calibrated discharge–depth–gate-opening relationships. The irrigation requirement exceeded the present supply level of 11 m^3/s for short periods at the beginning of the season during land preparation and planting, and towards the middle of the flowering stage, but it was sufficient to irrigate the whole system during the rest of the season. The average flow requirement for the entire season was estimated as 8.6 m^3/s. The irrigation requirement is high in the winter–spring season compared with the other two because of the low rainfall during this season.

Rotational supply. Under a 2-block, 4-day rotational schedule, each zone is irrigated on a 2-day rotation schedule so that irrigation of the whole system can be completed in 4 days. Here a supply ratio (SR) of two was used for each zone, given that water is supplied on 2 of 4 days in the irrigation cycle. The irrigation requirement exceeded 11 m^3/s for 33 days when Zone II is irrigated. It exceeded 12 m^3/s for only one or two days during the peak period and never exceeded 13.8 m^3/s (maximum availability). The average requirement is estimated as 8.4 m^3/s.

Under the 2-block, 7-day rotation schedule case, Zone I is irrigated for 3 days (SR = 2.33) and Zone II for 4 days (SR = 1.75). The requirement often exceeded 11 m^3/s for a few days in the soaking stage and mid stage of the season and while it was always below the maximum flow entitlement of 13.8 m^3/s, it exceeded 12 m^3/s towards the end of the season. The average requirement for the season is estimated as 8.6 m^3/s. This schedule was found to be more practical from the operator's point of view.

Field trial of alternative operational scenarios

Two of the simulated scenarios were tested in the field during the first week of January 2003 to assess their actual performance. The scenarios tested in the field consisted of irrigating the entire system using continuous flow and a rotational operation with a 2-block, 4-day schedule.

Continuous flow. The irrigation requirements were determined for each service area with a range of assumed tertiary efficiencies. Gate settings at each regulator were determined using the structure discharge ratings derived earlier in the project. Flow data were monitored and collected at measuring stations four times a day (0800h, 1000h, 1300h and 1500h) during the entire trial period. Gate openings were adjusted twice a day, based on the head difference at each gate. Current meter measurements were also made at selected locations to verify canal flows. The analysis of field data shows a more equitable distribution of water in the system compared with pre-intervention performance. The supply:demand ratio for the whole system was reduced to an average of 1.20, varying between 0.89 and 1.52 (Table 2).

Rotational supply. Because the trial had to be conducted during the irrigation season without disrupting the existing operation, the section of the system selected for the trial had to run seamlessly with the rest of the system. To satisfy this objective, the trial of rotational operation was carried out on a subsection of the system delineated by canal N25 that can be operated independently from the rest of the system. The service area was divided into two blocks to which water was supplied on a 4-day rotational schedule. Block 1 comprised service areas 2, 4 and 6, and Block 2 service area 7. An average supply:demand ratio of 1.18 was achieved during the trial. The coefficient of variation of supply:demand ratio between different service areas was found to be 13% for continuous supply and 5% for rotational operation. This outcome

represents a substantial improvement on the existing supply:demand ratios. The variability in supply to service areas was found to be significantly less than that observed in the 2001 and 2002 monitoring seasons. The trial was particularly useful in convincing IMC staff and other stakeholders that it is possible to improve the distribution of water by making simple changes to the existing operational rules.

Table 2. Supply:demand ratio for water during a field trial of alternative supply scenarios in the Cu Chi irrigation system, Vietnam

Service area	Supply:demand ratio	
	Continuous flow	Rotational supply
1	1.15	–
2	1.18	1.21
3	1.12	–
4	1.09	1.13
5	1.30	1.10
6	1.52	1.26
7	0.89	–
10	1.33	–
11	1.31	–
12	1.13	–
13	0.92	–
14	1.30	–
16	1.32	–
17	1.27	–
18	1.23	–
Average	1.20	1.18
Coefficient of variation	0.13	0.05

Water allocation and demand

Analysis was carried out to estimate the volume of water and the level of security with which the IMC can reallocate additional water to Ho Chi Minh City (HCMC) for industrial and urban use. A preliminary analysis of rainfall data was first carried out to determine water demand by the Cu Chi system at various levels of security. The probability of rain was analysed by conducting a frequency analysis of the annual data series. Based on the analysis, the annual rainfall expected at 90, 85 and 75% of probability of occurrence was calculated as 1622, 1654 and 1716 mm, respectively. Irrigation demands were then calculated using IMSOP in order to ascertain the level of security with which the system can meet irrigation demand and delivery of additional water to HCMC based on the current level of water allocation.

The analysis is conducted under the assumptions that the IMC has a water entitlement from the Dau Tieng reservoir system that is assured regardless of the availability of water in the system and the overall supply of water for Cu Chi irrigation must be maintained at the present level. According to the existing contract, the Cu Chi system is entitled to a supply of 13.8 m^3/s at the inlet of the system. Historically, however, the average flow at the head regulator has ranged between 8 and 8.5 m^3/s. Therefore, in order to include a range of possible water availability scenarios, the analysis is carried out for four flow-availability conditions at the inlet: 8, 11, 12 and 13.8 m^3/s.

Currently, the IMC is considering supplying 150,000 m^3/day of water to meet the demand from HCMC through canal N31A. To determine the effect of this volume of water reallocation to Ho Chi Minh City, the volume of water remaining after satisfying irrigation requirements at various levels of probability was calculated, as shown in Table 3. From the analysis, it can be observed that, at 90% probability of rainfall occurring, the company will be able to supply 1.34 times more water than the proposed 150,000 m^3/day, assuming flow availability at the head of the system of 8 m^3/s. The company will be able to supply 4.7 times the amount supplied at present if it can obtain an inflow of 13.8 m^3/s. At 75% probability of rain, the company will be able to provide 1.53, 3.27, 3.84 and 4.88 times the proposed supply at 8, 11, 12 and 13.8 m^3/s of inflow rate, respectively.

Table 3. Increase in surplus water at different inflow conditions in the Cu Chi irrigation system, Vietnam

Probability of occurrence (%)	Water available after irrigation supply at various levels of supply security			
	8 m^3/s	11 m^3/s	12 m^3/s	13.8 m^3/s
90	1.34	3.08	3.65	4.69
85	1.46	3.19	3.77	4.81
75	1.53	3.27	3.84	4.88

The weather and cropping mix prevailing in each of the three cropping seasons also affects the seasonal security of supply. The possible implications of the cropping mix were also analysed separately for each of the three cropping seasons, in order to evaluate the security of supply for each season. In particular, this is the case for the winter–spring season, which is more heavily dependent on irrigation. The average irrigation requirements at the head regulator at three different rainfall probabilities and three different levels of security of supply are shown in Figure 3. The weekly average discharge calculated exceeded the present average level of supply for 9 weeks in the winter–spring season. It is very clear from the analysis that, during the summer–autumn and main crop season, additional water can be safely diverted to Ho Chi Minh City if Cu Chi's irrigation requirements are to be met. The quantity that can be diverted during these two seasons is estimated at 67.55 MCM if the average available supply is 8.0 m^3/s and 186.80 MCM if the average supply discharge is 13.8 m^3/s.

Case study 2 – the Dan Hoai system

IMSOP modelling

The schematic of the Dan Hoai model includes main, sub-main and secondary canals (Figure 4). In IMSOP, individual tertiary canals are represented as canal offtakes. The Dan Hoai model comprises 84 nodes: 2 confluence nodes, 4 monitoring points, 3 cross regulators, 1 pump node and 98 offtakes. The system operation is organised through five substations under the management of the Dan Hoai IMC. Contracts for irrigation supply are drawn up between the substation and the agricultural cooperatives, based on cropping plans and assessed area. During land soaking and land preparation in spring, which is the period of highest water demand, the company operates all pumps for about 70% of the time and supplies water continuously for 28 days. There is an order of precedence for supply, starting at the head of the system, and a rotational irrigation schedule is practised between offtakes. After the land-soaking period, the canal is operated on a weekly rotation of 6 days supply and 1 day shutdown.

Analysis of past operation

Two years of comprehensive monitoring of system operation involving the two main cropping seasons in northern Vietnam allowed the calculation of actual water supply to sub-areas within the system, and assessment of the operational performance. In this process, the seasonal irrigation demand of the system was estimated using IMSOP for the water years 2000, 2001 and 2002, and compared with flow-monitoring data, in order to understand the shortcomings of the existing operation.

In spring 2000, the seasonal demand exceeded supply. Some 40.9 MCM was pumped from the main pumping station to meet a demand of 48.04 MCM.
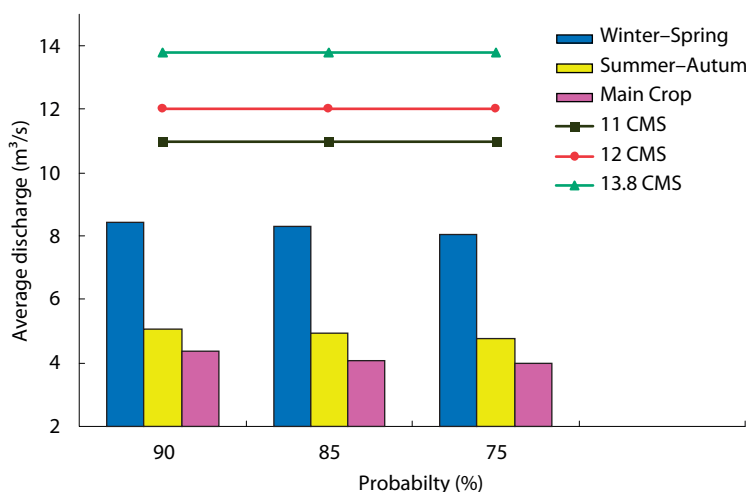

Figure 3. Average discharge required for meeting the irrigation demand at different levels of rainfall probability in the Cu Chi irrigation system, Vietnam

The supply:demand ratio at the Minh Khai cross-regulator and secondary canals N1 and N11 shows that the whole system is undersupplied (Table 4). In spring 2001, the quantity supplied from the pumping station exceeded the demand, but the supply was found to be less than demand in all the monitoring points except for the N2 canal. This analysis established that there were significant shortcomings in the operation of the system. The supply–demand analysis for the spring 2002 season shows that the whole system is undersupplied, with a supply:demand ratio that varied between 0.76 and 0.96.
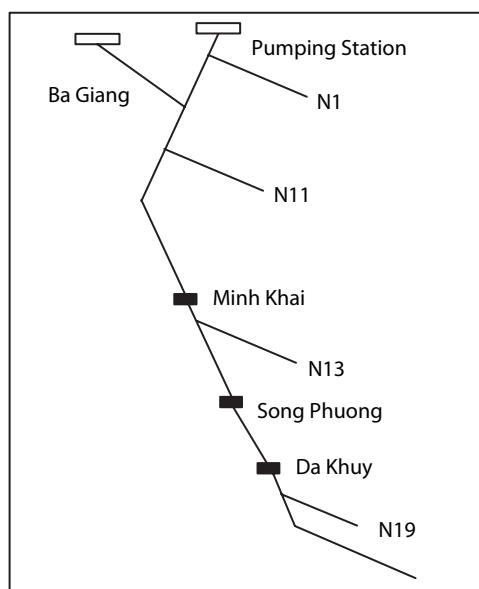
Figure 4. Schematic diagram of the Dan Hoai irrigation system, Vietnam

The comparison of supply and demand during the autumn season in 2000 and 2001 shows that there is consistent oversupply in the N2 secondary canal, which is located close to the Ba Giang sluice. The coefficient of variation between supply:demand ratios was estimated as 0.31 and 0.35, respectively, during these two years, significantly higher than for other seasons which relied less on water supplied from the pumping station.

The results of retrospective operational analysis in Dan Hoai suggest a consistent undersupply of water in the system. The overall distribution in the system is also very uneven, with some canals being oversupplied and some canals undersupplied. The inequity in distribution can be traced to problems with the hydraulic infrastructure, such as channel capacity, bank height, a number of illegal offtakes in the main and secondary canals, and malfunctioning of tertiary offtake gates. Moreover, the capacity of key cross-regulators is insufficient to pass peak demand flows to the downstream sections of the system.

Modelling of alternative operational scenarios

Alternative operational rules were simulated using IMSOP, with the aim of improving equity of supply to meet the level of crop water demand. Project staff held extensive discussions with IMC staff, research staff and other stakeholders, including farmers groups, to explore options for changing the operation of the system in order to improve its performance. Based on these discussions, three different scenarios were simulated and analysed using the model:

• continuous-flow irrigation in the entire system
• irrigating 2-block 4-day rotation (2B–4D)
• irrigating 2-block 7-day rotation (2B–7D).

Table 4. Comparison of supply:demand ratio in 2000, 2001 and 2002 at different points in the Dan Hoai irrigation system, Vietnam

No.	Monitoring location	Spring 2000	Autumn 2000	Spring 2001	Autumn 2001	Spring 2002
1	Pumping station	0.85	–	1.09	–	0.76
2	N2	0.86	1.44	1.23	1.41	–
3	Minh Khai	0.79	1.03	0.93	0.71	0.84
4	N1	0.79	0.70	0.76	0.77	0.96
5	N11	0.93	0.90	0.83	0.80	0.81
	Average	0.84	1.02	0.97	0.92	0.84
	Coefficient of variation	0.07	0.31	0.20	0.35	0.11

The service area was divided into two operational zones. Zone I comprises the upper half of the irrigation system from the pumping station to the Minh Khai cross-regulator, and Zone II the area from Minh Khai to the end of the main channel. Various combinations of continuous flow and operational zones (2B–4D and 2B–7D) were investigated over a range of assumed tertiary efficiencies. Under a 2B–4D rotational schedule, each zone is irrigated for two days so that irrigation of the whole system can be fully supplied in four days. Here, a supply ratio (SR) of two was used for each zone, given that water is supplied for two days in a four-day irrigation cycle. After calculating the irrigation requirement for each service area, the flow required at each regulator was estimated and the gate opening at each cross-regulator was then determined from previously calibrated discharge–depth–gate-opening relationships.

The modelling results revealed the following:

1. The capacity of the main canal is not sufficient to meet the peak requirement during land preparation and towards the flowering period if the whole system is irrigated continuously. Under this scenario, the water level at the Minh Kai cross-regulator should be kept at 8.65 to 8.8 m to irrigate the upper zone, causing inequity of water distribution in zone II due to insufficient head.

2. When the Minh Khai regulator is closed to raise the water level upstream, most of the offtakes at low elevation should be closed to provide sufficient head to raise the water level upstream. However, many of the offtake structures upstream of the regulator cannot be shut down due to poor condition.

3. Insufficient capacity of the main canal and major secondaries like N1 and N11 to meet the peak flow requirement restricted the adoption of any rotational schedule (2B–4D, 2B–7D).

4. The difference between actual pumping capacity and design pumping capacity is estimated as 35 to 45%, which indicates that the pumps do not have the capacity to supply sufficient water to adopt any long-term rotational schedule.

The capacity constraints of the main canal to meet the peak water requirement restricted the use of long-term rotational options. The modelling results also revealed shortcomings in the design criteria used in the recent upgrade of the main canal. Capacity constraints and inadequate hydraulic control severely reduce the ability to improve the level of service provided to irrigators.

Field trial of alternative operational scenarios

Currently, the system is operated on a rotational schedule, with the main canal running continuously for six days a week, with the supply rotated to the secondary canals and offtakes. After discussions with IMC staff and given the constraints imposed by the system hydraulic infrastructure, it was decided to select a single scenario for field testing. This consisted of irrigating according to the IMSOP-modelled operation based on the existing operational rules. The selected rules were field-trialled in the spring season (March 2003).

The IMSOP water requirements were determined for each offtake, at a range of assumed tertiary efficiencies. Based on this, the pumping requirements were estimated. An operation schedule was prepared for one week. This consisted of running the main canal continuously and rotating the secondary canals and offtakes. The schedule was prepared by considering the size and elevation of the offtakes. Flow data were monitored and collected at flow-measuring stations three times a day (0700h, 1100h, and 1700h) during the entire trial period. Gate openings were adjusted twice a day according to the head difference at each gate. The analysis of field data shows a more equitable distribution of water in the system. Supply satisfied the demand at all monitoring points with a supply:demand ratio ranging from 1.03 to 1.58 (Table 5). The trial convinced the IMC staff of the advantages of monitoring the actual flow throughout canals and adjusting the gates to irrigate so as to meet the crop water demand.

Table 5. Supply:demand ratio at different locations during field trial of alternative supply scenarios in the Dan Hoai irrigation system, Vietnam

Monitoring station	Supply:demand ratio
Pumping station	1.18
N1	1.13
N2	1.28
N5	1.30
N7	1.36
N9	1.12
N13	1.03
N15	1.58
Average	1.24
Coefficient of variation	0.13

As a result of the modelling study and subsequent field trial the following operational rules were proposed for the system:

- the area downstream of the Minh Khai cross-regulator should be irrigated first, and supply to secondary canals within this zone should be rotated
- N1 and N11 secondary canals should be supplied water continuously from the main canal, and supply to offtakes on these canals should be rotated
- while irrigating upstream of the Minh Khai cross regulator, the operation of the direct offtakes on the main canal must be rotated, first supplying the offtakes at lower elevation which should later be closed to irrigate the higher land.

Case study 3 – the La Khe system

Analysis of past operation

Performance analysis of the La Khe system (Figure 5) for 1996 was restricted by incomplete flow-monitoring data, but much was learned in terms of calibrating the model and getting an initial conception of the summer water-supply pattern. The estimated average demand was 432 mm/ha with an effective rainfall of 600 mm.
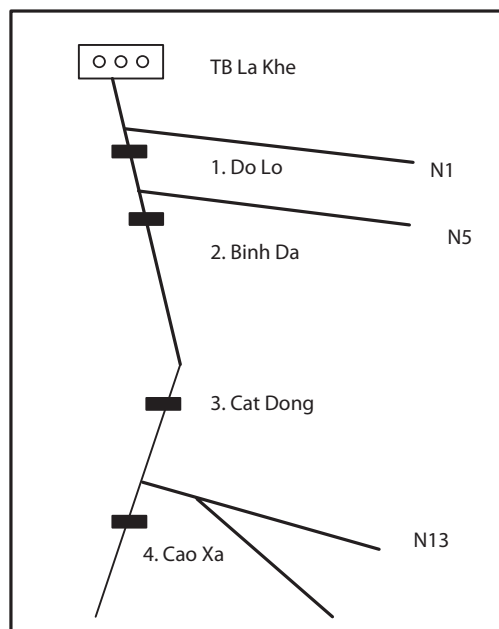

Figure 5. Schematic diagram of the La Khe irrigation system, Vietnam

The first season with sufficient data to complete the water balance was spring 1997. The comparison of IMSOP simulated demand and monitoring data showed that there was considerable oversupply of water to the first two of the major secondary channels (N1 and N1a) and smaller offtakes in the first two reaches of the canal, while the lower command area was able to meet only 55% of the demand. Supply:demand ratios calculated for each period reached values of 5 in N1 and 3 for the other channels (Table 6). To meet a calculated demand of 49.6 MCM (883 mm/ha) more than 70 MCM were pumped from the main station (1246 mm/ha). The seasonally corrected supply ratios are given in Table 6 to illustrate the disparity of service between the upper and lower reaches of the main canal in spring 1997, and the major losses implied in the first two reaches.

During spring 1998, overall supplies were approximately equal to demand, but measured supplies to the major upstream offtakes were less than required. The computed system demand for this season was estimated at 54.8 MCM. The analysis showed that the lower end of the system continued to get relatively poor water supply, although there was an improvement in volume but not water level control. The La Khe irrigation service (LKIS) appeared to 'over-respond' to the performance assessment for the spring 1997 season. Major losses and overuse are located in the first two reaches, where there is a high density of uncontrolled and un-gated offtakes.

Following the trial in April and a number of initiatives for sub-station staff, including incentive payments, the equity of distribution improved greatly between the upper and lower portions of the system in summer 1998. LKIS pumped considerably more irrigation water (33.95 MCM) than they would in an average year and distributed it more evenly with a supply:demand ratio of 1.03. They also benefited from not having to pump heavily for drainage. In general, supplies were less than calculated demand, and the 'controlled' upstream offtakes received relatively less, and considerably less than in previous times. LKIS appears to have compensated for its 'restriction' in water supply in the previous spring. At the same time, it is noteworthy that water distribution within N5 was better then it had been previously and that there were no complaints of poor service despite less water being delivered. Erratic water supply at N13 is thought to be the result of poor water-level control, but there are continuing problems with the completeness of manual monitoring data at N9 and N13.

Table 6. Supply:demand ratio for water, and its variation in different seasons, in the La Khe irrigation system, Vietnam

Service area	Supply:demand ratio		
	Spring 1997	Spring 1998	Summer 1998
Whole system	1.42	0.91	0.98
N1	1.52	0.62	0.96
Reach 2	–	–	0.81
N1a	2.19	0.63	0.46[a]
N3	1.02	0.66	0.80
N5	1.02	0.66	0.80
Lower CA (Reach 3 +)	0.58	0.66	0.79
N5b	–	0.98	0.93
N9	–	0.31[a]	–
Reach 4	–	0.61	0.66
N13	–	0.15[a]	0.34[a]
Reach 5	–	0.57	0.78
N13a	–	–	0.96
N13b	–	0.57	0.64
N15a	–	0.50	0.93
N15b	–	0.36	0.56
Average	1.29	0.58	0.76
Coefficient of variation	0.39	0.35	0.24

[a] = missing data

Modelling of alternative operational scenarios

Rotation was investigated for spring rice cultivation, using long-term average weather and rainfall conditions. Promising scenarios were re-examined using more extreme wet and dry conditions, to obtain some idea of the sensitivity of capacity constraints (Turral et al. 2002).

Various combinations of 'blocks' (2–4) and 'on-time' (1–7 days) were investigated, over a range of assumed tertiary efficiencies (60–80%). In summary, the findings were as follows:

- Peak water requirements at land-soaking under all scenarios exceeded the capacity of the major secondary channels (N1, N1a, N3, and N5).
- Peak water requirements at land-soaking frequently exceeded the channel capacity in the second reach of the main canal and sometimes in the third reach. The capacity of the second cross-regulator at Binh Da was also insufficient.
- Peak water requirements in the late season (at flowering time) can be accommodated under a 2 block, 4+4 day rotation, except in extremely dry years when demand may exceed regulator capacity at Binh Da and Cao Xa.

Vietnam Institute for Water Resources Research (VIWRR) staff proposed an alternative scenario which overcomes the problems of limited capacity in the secondary canals: supply the larger canals continuously while rotating the smaller ones (which have relatively larger capacities). Thus, the main channel operated on continuous flow during the entire operation period. These scenarios were modelled on 4, 5 and 7 day on-times, with the two groups of offtakes and with the system in continuous operation. No system constraints were observed during either the land-soaking period or late season. However, the existing capacity constraint in reach 2 and through Binh Da regulator still applies.

When the canal was operated in an 8 days on–8 days off, with a 4+4 rotation of water delivery, the capacity of the system was tested at the third cross-regulator, Cat Dong. Since there is a probability of rain in the off periods, the constraint may not eventuate. Nevertheless, if the operation cycle stretches out to 12 days shut down followed by 12 days (6+6) rotational supply, then the second and third cross-regulators both limit supply to 15–25% less than the computed requirement.

Field trial of alternative operational scenarios

A trial rotational operation was organised at the end of the spring rice season in 1998, from 25 April to 5 May. The service area was divided into two blocks for operation. Block 1 comprised the upper half of the irrigation system, from the pumping station to the second cross-regulator at Binh Da. Block 2 covered the area from Binh Da to the end of the main channel.

Block 2 was supplied with water first, with some additional supply to the large secondary channels in Block 1 (N1, N1a, N3 and N5), in order to overcome the capacity constraints observed in these channels under full rotation. Each block received water for 5 days. LKIS and VIWRR staff took control of the operation of the major secondary channels in the system, but were unable to fully control the smaller secondary offtakes.

The average calculated water demand for the 10-day trial period, calculated by IMSOP (assuming that all planting dates and soil-type descriptions are correct, and that average tertiary offtake efficiency is 80%), was 1194.4 m^3/ha (Table 7).

Table 7. Comparison of seasonal and field trial water distribution (m^3/ha) throughout the La Khe irrigation system, Vietnam, spring 1998.

Location/reach	Whole season		Field trial		
	Demand (m^3/ha)	Percentage of total supply	Demand (m^3/ha)	Supply (m^3/ha)	Percentage of demand
Average of system	7920	100	1194.4	1462	122
Reach 1	11196	141	1252	2046	163
Reach 2	8741	110	1234	1735	141
Reach 3	6901	87	1271	943	74
Reach 4	5253	66	1275	997	68
Reach 5	7028	89	1335	1359	78
N1	7461	94	1093	1101	101
N1A	4843	61	944	803	85
N3	6432	81	1076	864	80
N5	6184	78	1093	936	87
N5B	6594	83	1093	1004	92
N13A	6928	87	1350	901	67
N13B	5392	68	1274	1023	80
N15A	3993	50	1274	1167	92
N15B	3091	39	1274	1012	79

During the field trial, water elevations at the end of the canal were recorded at 5.03 m above mean sea level (amsl). The design value is 4.8 m amsl with commonly observed values of less than 4.5 m.

The results of the field trial revealed that:

- supplying water to the downstream reaches first ensured a more equitable supply
- the distribution of water between the upper and lower half of the system was very uneven over the whole season
- during the field trial, Blocks 1 and 2 and downstream secondary canals almost satisfied the water demand
- there are many uncontrolled secondary offtakes and their water usage is very high
- average water use is skewed by a high level of losses in the first two reaches, both through leakage and through uncontrolled offtake.

Conclusions

In this paper, a package of operational improvements designed to enhance the performance of publicly managed irrigation schemes is presented. The package includes a GPS-based survey of existing infrastructure, calibration of irrigation-control structures, the implementation of the operational model to simulate the operation, retrospective analysis of the system operation, monitoring of the existing operation and field-trial of alternative operational rules. A steady-state operation model called Irrigation Main System OPeration (IMSOP) was adapted to model the system operation. The package was applied in three irrigation systems in Vietnam to improve the technical operation of the irrigation delivery system.

In Cu Chi, the retrospective analysis showed that the supply:demand ratios varied between 1.68 and 2.51 for the entire system and between 3 and 5 between individual service areas under the pre-intervention operation rules. These disparate deviations between supply and demand, indicate that the system operation is carried out without consideration of the actual crop water demand and proper canal regulation to achieve supply equity. Two new scenarios based on continuous flow and rotational supply were selected, simulated, analysed and tested in the field. The analysis of the field data yielded an average supply:demand ratio of 1.20 for continuous flow and 1.17 for rotational operation. A comprehensive

analysis of water reallocation to Ho Chi Minh City for urban and industrial purposes, and its effect on the security of supply on the Cu Chi system, showed that, at 90% of probability of rainfall occurrence, the IMC will be able to supply three times more than the proposed 150,000 m^3/day assuming a flow availability of 11 m^3/s at the head of the system.

In Dan Hoai, the retrospective analysis showed large deviations between supply and demand, with a consistent undersupply of water in the system. The overall supply:demand ratio varied between 0.79 and 0.93 in spring 2000, 0.76 and 1.23 in spring 2001 and 0.76 and 0.96 during spring 2002. The study also revealed that the highly inequitable distribution can be traced to inadequate channel capacity and hydraulic control, the large number of illegal offtakes in the main and secondary canals, and malfunctioning of tertiary offtake gates. Based on the discussion with IMC staff, a single scenario consisting of IMSOP-scheduled flows following the existing operation rules was selected and field-trialled in the 2003 spring season. The analysis of the field data shows a more equitable distribution of water in the system, with an average supply:demand ratio of 1.24.

At La Khe, the supply–demand analysis showed wide variations between supply and demand, with oversupply in some instances exceeding 400% of crop water requirement. A 2-block 10-day rotational scenario was simulated, analysed and tested in the field. The field trial showed that rotational schedules yielded significant improvements in the level of equity among users throughout the system. The relative water supply was much more even between Blocks 1 and 2, and the downstream secondary canals almost satisfied demand.

The following important lessons have been learned for the future applications of the process to systems other than the three case studies:

- Early establishment of flow monitoring is very important in providing sufficient and timely information on system and management performance. The establishment of automatic flow-monitoring devices eases the process but they need careful calibration and maintenance.

- There is a need to develop an improved mechanism for planning and coordinating the crop area development at the offtake level and transferring the information to the IMC at the start of the season for the demand calculation.

- Establishment of effective flow control in both main and secondary channels is of major importance. Clear rules and procedures for the best operation of existing regulators and offtakes need to be developed and agreed early in the process.

- The application of the model needs adequate description of the irrigation system in the form of a network. Extensive survey is required for this process and can be speeded-up by application of modern technology such as GPS.

- Key participation from the stakeholders is essential for successful implementation of the model, and IMC staff must therefore be trained in data collection and model implementation at the earliest possible stage.

- Developing clear and simple operational scenarios can reduce very large water losses and the negative environmental impacts of over-irrigation. But this needs better understanding of the system regulations and constraints, and consultation with the farmers' groups is essential.

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Operational and Resource-Use Performance in the Cu Chi Irrigation System

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Abstract

Understanding why measuring and calculating water-use performance is important can best be undertaken with reference to an example. To that end, an exercise in water-use performance was undertaken on a site in the Cu Chi irrigation system. The choice of a site is explained, along with the tasks and calculations needed to complete the exercise. The results obtained in this analysis can readily be compared with those obtained from a wider assessment of farmers in the irrigation scheme. Rice productivity per unit area and per unit irrigation water is lower than in other Vietnamese systems and significantly lower than in other Asian countries. However, the productivity of maize and peanuts is similar to average yields in other Vietnamese systems. The water productivity of maize and peanuts was found to be very high compared with rice. Output of irrigation water in the winter–spring crop was US$0.04/m^3 for rice, US$0.15/m^3 for maize and US$0.11/m^3 for peanuts.

Background and Objectives

Efficiency gains and improvements are not only achieved by having a reliable supply of water provided by a well-managed entity. They can also be realised by users finding better ways of employing the water they currently receive. For people using water, a reasonable adage to follow may well be that producing more from either the same quantity of water, or less water, will result in an improvement in efficiency. In order to invoke this adage, an analyst must have some idea of the current rate of water-use efficiency. Once this rate is known, it can be compared with other research on water-use efficiency to work out the degree of inefficiency that is evident, if any, before improved flows are recommended. The purpose in this paper is to outline a method of assessing the degree of water-use efficiency and to apply it to a specific site.

This method was applied to a site within the Cu Chi irrigation scheme between 2001 and 2003. Both land and water productivity were assessed. Quite simply, the ability of the irrigation system to turn land and water resources into marketable product was assessed. In addition, the adequacy of irrigation and water supply (including rainfall) to meet crop water requirements was gauged. The main irrigation canal supplying water to the study site was lined in the 2002 monsoon season. As a consequence, the effect of lining on the canal performance was also evaluated. The methodology used, the main findings and their implications for management improvement are presented in the following sections.

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Method

The procedure for assessing water-use performance involves selecting a suitable site within an irrigation scheme. The site is then segregated into different components and the amount of water supplied to each segment, by both irrigation and rainfall, is measured. Within each segment, the activities of farmers, the areas planted and yields are monitored. From this base, the water balance and performance indicators can be calculated.

Site selection

It is not possible to assess the performance of a whole irrigation scheme continuously. While the cost of doing so would outweigh the benefits, there is no necessity to do so. What is required is to select a portion of the scheme that can be reliably assessed. It must not be too large and yet must, in some sense, be representative of the whole scheme. In particular, it must be possible to measure the amount of water entering and leaving the site. The analysis must be conducted over a sufficiently long period to capture changing climatic conditions. This is usually one crop year. If the intention is to investigate how some improvement may benefit water-use efficiency (say by canal lining), then it may be necessary to observe a longer period of water use; one before the improvement and one after it.

The study in Cu Chi was carried out from August 2001 to August 2003 at an area serviced by irrigation canal N43-6 and drainage canal T43-6 of the irrigation scheme (Figure 1). The area of the site selected was approximately 55 ha, of which 49 ha were arable. The cropping calendar of the study site consisted mainly of three seasons: winter–spring from December to March; summer–autumn from April to July; and the monsoon season from August to November. Farmers grew maize and peanuts in relatively elevated land and rice in relatively low land in the winter–spring season, whereas in summer–autumn and monsoon, farmers grew only rice. (For more details on the seasons in the south of Vietnam, see Malano et al. (2004)).

Irrigation and drainage canals within the study site divided it into three sub-areas:
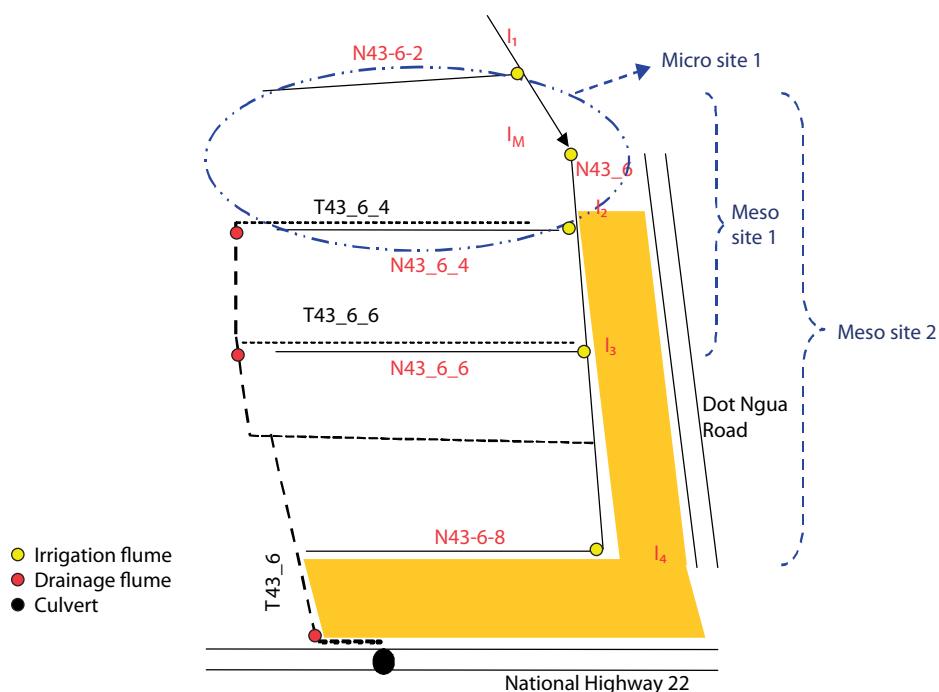- micro site 1, irrigated by branch canal N43-6-2 and drained to T43-6-4

Figure 1. Schematic layout of the study area in the in the Cu Chi irrigation system, Vietnam

- micro site 2, irrigated by branch canal N43-6-4 and drained to T43-6-6
- micro site 3, irrigated by branch canal N43-6-6 and N43-6-8 and drained to T43-6.

N denotes canals supplying water, and T drains emptying the scheme.

Micro sites 1 and 2 were generally at a higher elevation than micro site 3. Within micro site 3, land was higher along the irrigation canals of N43-6-6 and N43-6-8, while the middle of the site was lower, creating a wide, stagnated zone in the middle.

As will be explained in later in this paper, it is necessary at certain stages to combine some sites in order to compute the water balance. Micro sites 1 and 2 can be placed into what is termed 'meso' site 1, while all three micro sites can be collapsed into meso site 2. Such groupings do not violate the underlying basis of the analysis.

Monitoring water and climatic parameters

It is important to measure the water entering and leaving the site and how it is distributed to each micro site within the site. This is achieved using long throat flumes (Tony et al. 2000). These flumes were installed at the inlet of each irrigation canal (N43-6-2, N43-6-4, N43-6-6 and N43-6-8) and at three locations along the drainage canal T43-6 (downstream of T43-6-4, at T43-6-6 and at the end of T43-6). Thus, it is possible to measure the discharge of the irrigation intake to, and drainage from, each micro site (Figure 1). The upstream water depth was recorded automatically at 30-minute intervals using water level probes to calculate the discharge through the flumes. The total irrigation and drainage water of any period is calculated by integrating the discharge over the measured time.

In order to accurately measure water use, it is necessary to account for:
- seepage loss, which is the amount of water that is lost in the canals themselves
- the water that is in the soil
- any changes in climate.

A measuring flume (I_M in Figure 1) was installed in the main canal (N43-6) to assess seepage loss, which is calculated as the difference between the discharge at I_M and the sum of discharges at measuring flumes I_2, I_3 and I_4 (see Figure 1). Groundwater-table tubes and percolation rings were installed at five points diagonally along the study site to assess the amount of water in the ground.

They were monitored twice weekly during the study period. Daily weather data (rainfall, temperature, relative humidity, radiation, wind speed) were recorded at an automatic weather station, which was installed 3 km from the study site.

Monitoring farming activities, planted area and crop yields

Water is an input into the crop production process. To assess performance, it is necessary to evaluate the amount produced. Of interest is the yield, or the output per unit of area. A higher yield for a given quantity of water used can be construed to mean that performance has improved. As water use is not the only way of improving performance in a dynamic farming system, it is essential to observe the practices used to produce output. Again, it is necessary to select representative activities from the almost unlimited range available.

Using a land-parcel map, crop yields were assessed by conducting farm surveys of 22 of 39 randomly selected farmers at the end of each cropping season. Within the surveyed farms, crops were cut and monitored on 5 m^2 on 4 to 10 randomly selected rice fields, after each rice-growing season. In addition, 6 to 8 fields with upland crops were monitored in the winter–spring growing season. The data from the survey and the crop cuts were used to calculate the average crop yields.

Computation of water balance components

The 'water accounting' procedures proposed by Molden et al. (1998) were carried out for each cropping season, for each micro site. Quite simply, these procedures account for where the water goes in the system. It is important to assess whether 'reuse' occurs during this process. The water accounting for each site can be calculated using equation (1). All terms in equation (1) are expressed in millimetres (mm) of water, over the area of interest.

$$(I + RF) - (ET_{crop} + ET_{fallow}) \qquad (1)$$
$$- (D + DP) - Out_{un} = \Delta S$$

where: I = irrigation water

RF = rainfall

ET_{crop} = evapotranspiration from the cropped area

ET_{fallow} = evapotranspiration from the non-cropped area

D = drainage

DP = percolation

Out_{un} = other unaccounted outflows to surrounding areas (e.g. seepage from canals, lateral water movement from the study site to surrounding fields.)

ΔS = change in water storage in the site.

The water-balance components were calculated for the composite sites comprising micro sites 1 and 2 (meso site 1) and micro sites 1, 2 and 3 (that is meso site 2) (Phong 2002; Tuong 2002).

The ET_{crop} was calculated from weather data using the Penman–Monteith equation (Allen et al. 1998) for the crop under study. To evaluate equation (1), it was necessary to make several assumptions. These were as follows:

- In the winter–spring season, most of the fallowed land was dried. To account for this, a daily rate of ET_{fallow} was needed, and was assumed to be equal to half of the daily rate of ET_{crop} for peanuts.
- In the monsoon and summer–autumn seasons, most of the fallowed land was flooded and covered with aquatic weeds. As a consequence, the change in water storage in the site (ΔS) was assumed to be zero. It was also assumed that ET_{fallow} was the same as ET for rice.
- At the start of the winter–spring season, a field often has water in the soil at a capacity necessary for growing upland crops (i.e. a 1–3-cm-deep water layer for rice transplanting). Thus, at this time the change in water storage in the site (ΔS) was assumed equal to 50 mm, to take into account for the amount of water required for saturation in the soil.
- At the time of harvest of the crop in winter–spring, there is usually no standing water and the soil is rather dry. Thus, the change in water storage in the site (ΔS) was assumed to be equal to –50 mm.
- The only term in equation (1) that could not be measured or computed is out_{un}. Thus, this term was assumed to be a residual that is used to close equation (1).

Computation of performance indicators

While performance can be measured in many ways, the usual method is to calculate the amount produced (output) from a given unit of input. The unit of input in most economic or agronomic studies is by area. However, in a hydrological study such as this, it is perhaps more relevant to use some quantity of water as the unit of input. Marsh et al. (2004) provide an interesting comparison on the choice of the input unit. In that paper, a unit of land is preferred over water, as that is the standard practice in gross margins analysis.

In this study, output was measured in terms of crop yield per unit of either: cropped area; command area; water consumed; irrigation water; or water supply (irrigation + rainfall). Within an area, there can be many crops grown (e.g. rice, maize, peanuts etc.). Thus, the 'yield' can be assessed for each specific crop over its area (i.e. kg of rice/ha), which can in turn be converted to the value of outputs per unit cropped area ($/ha) by:

$$
\text{Output per unit cropped area (\$/ha)} = \frac{\sum_{i=1}^{n} Y_i A_i P_i}{\sum_{i=1}^{n} A_i} \tag{2}
$$

In some cases, the cropped area is not as large as the expected or the planned 'command' or 'designed' area. Thus, it is important also to indicate the value of the product per unit command area:

$$
\text{Output per unit command area (\$/ha)} = \frac{\sum_{i=1}^{n} Y_i A_i P_i}{CA} \tag{3}
$$

where i = crop type

n = number of crops

A = crop area (ha)

Y = crop yield (kg/ha)

P = crop price ($/kg)

CA = command area.

For more details on these procedures see Molden et al. (1998).

The relative water supply (hereinafter called RWS) was computed as the ratio of the total water supply to crop demand:

$$
RWS = \frac{I + RF}{ET_{crop} + DP} \tag{4}
$$

Similarly, the relative irrigation supply (herein-after RIS) is the ratio between irrigation supply and the irrigation demand:

$$RIS = \frac{I}{ET_{crop} - RF_{eff}} \qquad (5)$$

where all variables are as defined for equation (1).

The effective rainfall was calculated using the fixed-percentage of rainfall method of IMSOP (Turral et al. 2002) and is given as

$$RF_{eff} = 0.67(RF - 6) \qquad (6)$$

where RF = measured rainfall (mm/day).

The above equation can be evaluated between upper and lower bounds so that:

if $RF > 75$ *then* $RF_{eff} = 75$ *and if* $RF < 10$ *then* $RF_{eff} = 0$

Water Balance Components

Variation between sites

The components of the water balance at different sites in the winter–spring season of 2002–03 are shown in Figure 2. In this season, there was no rainfall. The irrigation in micro site 1 was the highest (1400 mm, compared with 1000 mm in other micro sites). As a result, the irrigation depths in meso site

1 (aggregation of micro sites 1 and 2) and meso site 2 (aggregation of the 3 micro sites) were approximately 1100 to 1200 mm. The average ET over the command area was between 260 and 300 mm. The differences in ET among the sites were attributed to different portions of the areas used for different crops (rice versus upland crops) and land that was fallowed.

Drainage and the unknown outflows (the closure term of equation (1)) varied significantly among the micro sites. These differences can be attributed to variations in the topography. The amount of drainage water from micro site 3 was lower than those in micro sites 1 and 2. The low-lying area in the middle of micro site 3 might have collected some water, making moisture more available to the plants in that area. The unaccounted outflow was highest in micro site 1. This could be due to the lateral movement of water from the site to the lower micro site 2, and the unaccounted seepage from N43-6-2 to surrounding areas. Likewise, the unaccounted seepage from N43-6-8 to the surrounding land may explain the negative value of the closure term in micro site 3. A positive value of the closure term in micro site 2 indicated that it might have received the net inflow due to lateral water movement from micro site 1. Thus, it can be concluded that there were considerable flows amongst the sites.
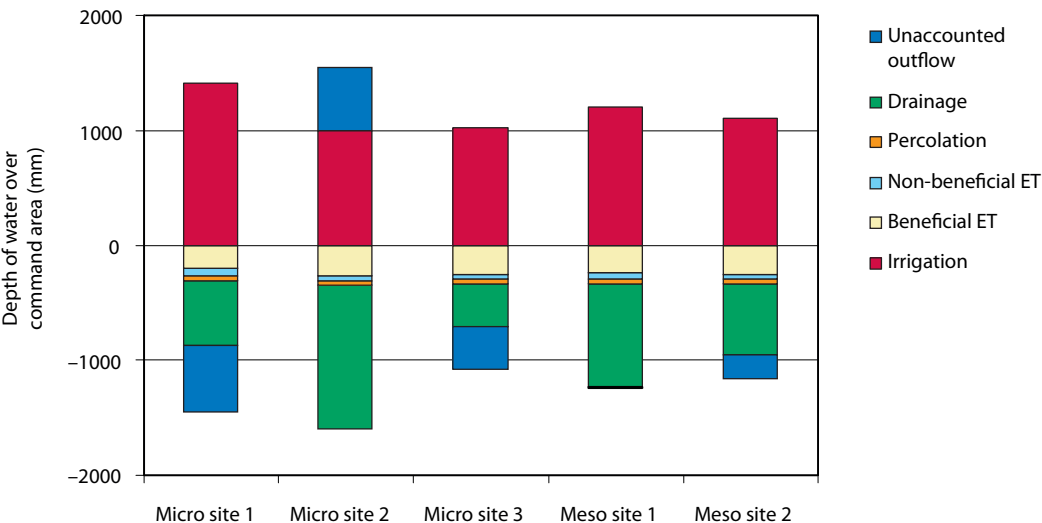

Figure 2. Water balance components monitored during winter–spring 2002–03 in the study area in the Cu Chi irrigation system, Vietnam

Variation across seasons

The variation of water balance components in the monitored seasons is shown in Figure 3. The irrigation depths were higher in the winter–spring season than in the other seasons. This could be due to the lower evaporative demand and greater rainfall that occurs in the monsoon and summer–autumn seasons. Low irrigation depths in the monsoon season of 2002 were possibly due to the closure of irrigation facilities for canal lining operations. This anomaly should not be reflected in any changes in irrigation canal management. Irrigation amounts in the winter–spring season of 2002–03 were higher than that in the corresponding season of 2001–02. This might reflect the better conveyancing capacity of the canals after lining.

Relatively high drainage values, especially in the monsoon and summer–autumn cropping seasons, could be due to the fact that water supply was far in excess of water demand. In the winter–spring season of 2002–03, higher irrigation amounts led to higher levels of drainage than those recorded in the winter–spring season of 2001–02. The unaccounted water flow was only a small part of the total water input.

Such a result is a good indicator of the accuracy of the measurement and its subsequent computation.

Effect of canal lining: seepage from main canal

The seepage loss in sections of N43-6 along the study site is presented in Table 1. Before the canal was lined in the winter–spring season of 2002, seepage loss in the main canal of N43-6 was measured at a high of 10–11 m^3/day/m length of canal, or 3.9 m^3/day/m^2 canal wetted area. After lining, seepage per day per metre length and per unit of wetted area, fell by 33%. Thus, it could be argued that lining was effective in reducing seepage from the canal. This translated into a reduction in canal seepage loss computed over the service area from about 8 mm/day to 5 mm/day. This was higher than percolation, which was measured at 2 mm/day, and crop evapotranspiration, which was found to be 4–5 mm/day. Thus, it can be concluded that the water loss along the canal from seepage was a major component of water loss in the study area and could be considered to be a major contributor to the amount of drainage water leaving the scheme (see Figures 2 and 3).
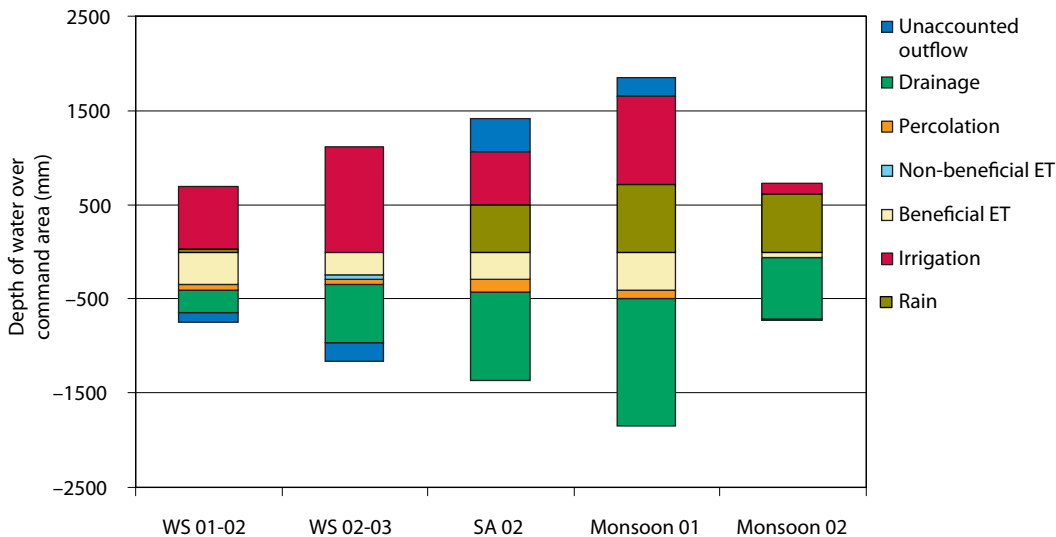

Figure 3. Water balance components monitored during different cropping seasons in the study area in the Cu Chi irrigation system, Vietnam

Table 1. Volume conveyed by and seepage (S) from the main canal N43-6 (section from I_M to I_4, Figure 1) in the Cu Chi irrigation system, Vietnam

	Winter–spring 2001–02	Summer–autumn 2002	Winter–spring 2002–03
Seasonal total volume (m^3)	329,737	377,707	217,869
Volume per day (m^3/day)	3,297	3,777	2,179
Average daily S over service area (mm/day)	7.6	8.7	5.0
S per day per m of canal length (m^3/day/m)	10	11	7
S per day per canal wetted area (m^3/day/m)	3.9	4.2	2.7

Resource-use Efficiency Indicators

Output per unit cropped area

It was found that, on average, the outputs per cropped area in different cropping season were as follows:

- rice yielded from 2.1 to 2.8 t/ha
- maize yielded 4.4 to 5.0 t/ha
- peanuts yielded 1.8 to 2.5 t/ha.

Farmers received a gross income of between US$224 and US$280 per ha for rice, US$577/ha to US$827/ha for peanuts and US$900/ha to US$1000/ha for maize.

While the maize and peanut yields were found to be similar to the average yields in the Ho Chi Minh City area, rice yields in the study site were found to be much lower than the average rice yield across the irrigation scheme (CCIC 2003). Consequently, the average gross income in the study area was less than that computed for all farmers in the Cu Chi irrigation scheme. In Cu Chi, average farm gross margins were US$363/ha to US$415/ha for rice, US$979/ha for peanuts and US$1361/ha for maize. Income from rice per hectare was also estimated to be lower in Cu Chi than that in Malaysia (Cabangon et al. 2002), Nigeria and Sri Lanka (Molden et al. 1998) and China (Dong et al. 2001; Moya et al. 2001).

Output per unit of irrigation water, and output per unit of water supply (including rainfall)

The ET productivity of rice was found to be low, at between 0.48 kg/m^3 and 0.71 kg/m^3 in the study area (Table 2). The ET productivity of peanuts reached 0.83 kg/m^3 and maize reached 1.64 kg/m^3. The water productivity of maize and peanuts was found to be very high, when compared with that of rice. Output of irrigation water in the winter–spring crop was US$0.04/m^3 for rice, US$0.15/m^3 for maize and US$0.11/m^3 for peanuts. For rice, this was higher than in the summer–autumn season, where US$0.02/m^3 of water was earned, and in the monsoon season, where only US$0.03/m^3 was earned. This result was derived from the higher crop yield obtained in the winter–spring season.

Relative Water Supply and Relative Irrigation Supply

Variation among sites

The RWS and RIS in different micro and meso sites in the winter–spring seasons of 2002–03 are shown in

Table 2. Water productivity of the study site in the Cu Chi irrigation system, Vietnam

Parameters	Winter–spring 2001–02			Monsoon 2001	Monsoon 2002	Winter–spring 2002–03			Summer–autumn 2002
	Rice	Maize	Peanuts	Rice	Rice	Rice	Maize	Peanuts	Rice
kg/m^3 of ET	0.60	1.64	1.83	0.64	0.71	0.59	1.43	0.58	0.48
kg/m^3 of irrigation	0.37	0.69	0.35	0.27	0.37	0.20	0.34	0.29	0.21
kg/m^3 of rainfall+irrig.	0.36	0.67	0.34	0.16	0.18	0.20	0.34	0.29	0.14
$/m^3 irrigation	0.04	0.15	0.11	0.03	0.03	0.02	0.07	0.09	0.02
$/m^3 rainfall+irrig.	0.04	0.14	0.11	0.02	0.02	0.02	0.07	0.09	0.014

Figure 4. The two performance indicators had the same value because there was no rainfall during that season. It can be inferred that the amount of water supplied was 2.4–3.4 times higher than required. The RWS and RIS values were higher at micro site 1 than at micro sites 2 and 3. They were also higher in meso site 1 than in meso site 2. This was probably due to the higher elevation of micro site 1.

Variation across seasons

The variation in RWS and RIS of meso site 2 during the monitored seasons is shown in Figure 5. The RWS ranged from 1.6 to 3.1, and the RIS was from 1.5 to 9.5. The RWS and RIS were particularly high in the monsoon season of 2001 (at 3.3 and 9.5, respectively). This was because, despite very high rainfall (710 mm), low ET and irrigation water requirements, the system maintained a very high irrigation discharge. The RWS and RIS were not high in the monsoon season of 2002, because the irrigation system was shut down for canal lining, and because a low rainfall was recorded. In all seasons, the RWS and RIS were greater than 1, which is indicative that the water supply far exceeded the evapotranspiration rate. Thus, it can be concluded

that the irrigation supply far exceeded irrigation demand. In other words, there was large amount of excess water during the study period.

The RWS and RIS in the winter–spring season of 2002–03 were higher than those of the corresponding season of 2001–02; that is, excess water in the winter–spring season of 2002–03 was more than in the winter–spring season of 2001–02. This occurred when the seepage from the irrigation canal in the winter–spring season of 2002–03 was less than in the winter–spring season of 2001–02. This could be due to canal lining (see Table 1). The reduced seepage loss from the canal has not been translated into better water control in the sub-system under investigation.

The excess of irrigation water compared with crop requirement can be seen again in Figure 6. Water intake in N43-6-4 on many days was two or three times higher than the daily ET during the dry season of the winter–spring season of 2002–03. The inadequate service of the control structures (due to loss or damage of the control gates) and poor field water-management practices (e.g. uncontrolled flooding) could have caused irrigation water wastage and lowered the crop water productivity considerably.
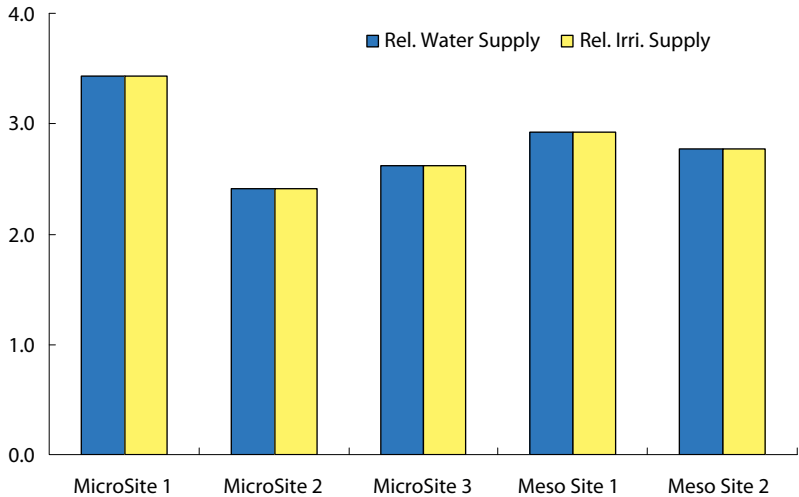
Figure 4. Relative water supply and relative irrigation supply estimated across different scales in the study area in the Cu Chi irrigation system, Vietnam
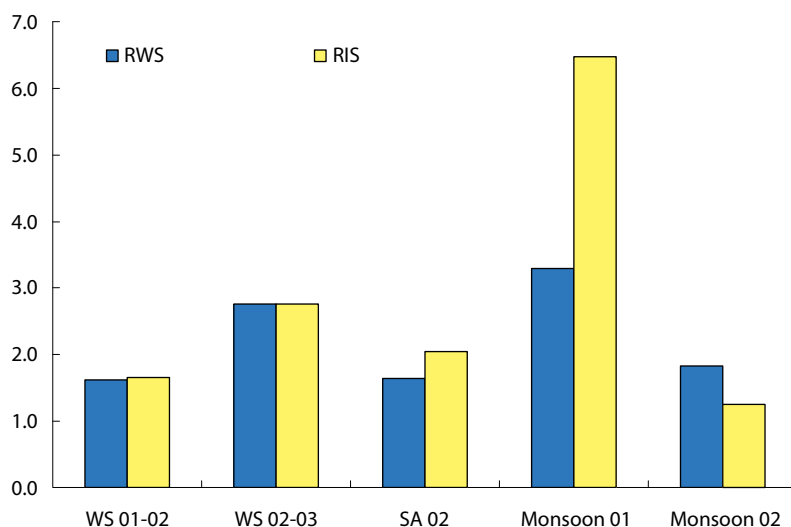
Figure 5. Relative water supply (RWS) and relative irrigation supply (RIS) estimated for different cropping seasons in the study area in the Cu Chi irrigation system, Vietnam
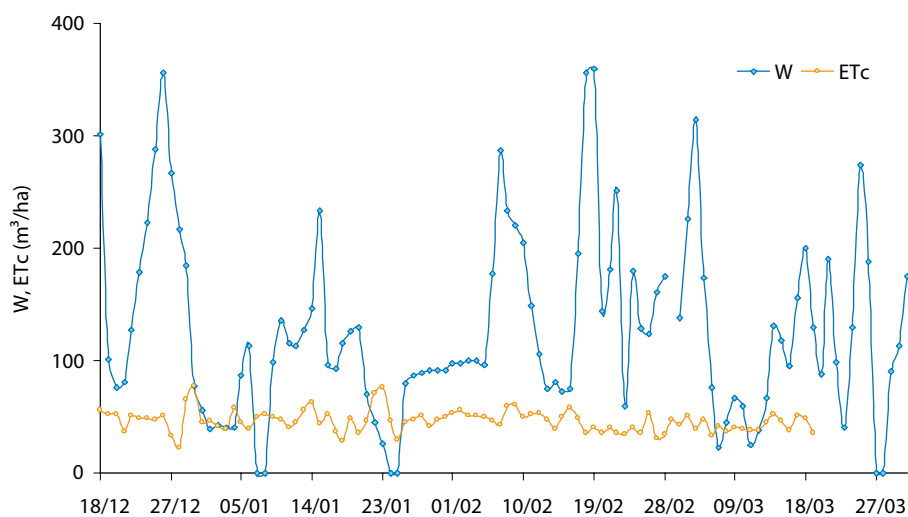

Figure 6. Irrigation delivery from N43-6-4(l) and evapotranspiration during winter–spring 2002–03 in the study area in the Cu Chi irrigation system, Vietnam

Conclusions

In this study, the process of assessing resource-use performance from measurements of water-balance components within the Cu Chi irrigation system is described. The physical output per unit of cropped area and per unit water consumed (ET) for maize and peanuts were comparable to those in other parts of Asia, while for rice they were much lower. The main reason for a low ET water productivity of rice was its low yield.

The economic output per unit of water supplied to the study area was lower than comparable irrigation systems in Asia. Rice productivity per unit area and per unit irrigation water was found to be lower than in other Vietnamese systems, while the productivity of maize and peanuts is similar to average yields in other Vietnamese systems. Water productivity of maize and peanuts was found to be very high, especially compared with rice. Output of irrigation water in the winter–spring crop was US$0.04/m^3 for rice, US$0.15/m^3 for maize and US0.11/m^3 for peanuts.

The high values for the RWS and RIS indicate that there was no water shortage in the study site. Further, it can be concluded that the water supplied through irrigation could be much reduced, without affecting crop yield. This implies that reducing the amount of irrigation could therefore increase the output per unit of water supplied (through irrigation) considerably. Another way to increase the economic output per unit of area or per unit of water supplied is to replace rice growing with peanut and maize production. This option is, however, contrained by a very high groundwater table in the study area. Reducing the water supply could reduce seepage losses from the canal and therefore reduce the groundwater table. Further improvements could be made to the groundwater table, especially if shallow wells are used to replace the irrigated supplies of water. Diversion of water from agricultural uses towards higher value usage, will not only increase the output per unit water supplied, but also will help reduce the flooding/submergence problems that limit the cultivation of high-value upland crops in the area, especially in the low-lying areas of micro site 3.

Lining canals reduced seepage losses and increased the conveyance capacity of the main canal. But it did not increase the output per unit of water supplied or irrigation application efficiency. To capitalise on the improvements made to the main canal, it is necessary to couple them with other improvements, such as better sluice-gate management in the main canal and the rebuilding of intake gates from branch irrigation canals. Such actions may allow better matching of water supply to the demand at each micro site.

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Assessing the Impacts of Water Flows on Users: a Gross Margins Analysis of Farms

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Abstract

Water flows are regulated for a purpose. To understand and improve the flow of water from a central storage to its intended user is only part of the story. The impacts improved flows of water will have, will not only be experienced by those who run the schemes, but also by those who use them. A clearer understanding of this effect can be seen from studies on measuring resource-use performance. Consequently, it is necessary to measure, in some objective manner, the impacts any current or expected water flows may have on water users. This needs to happen at a wider level than what was measured when resource-use performance was evaluated. Given that most regulated water flows are used by farmers who produce irrigated crops, a technique that complements and enhances farmers' planning horizons is required. One such technique is gross margins analysis. Further, as water is not the only factor involved in farming, a technique that can encompass all farm activities is required. Gross margins analysis is such a technique. It was found that variability in water availability has little effect on the yields and incomes of farmers in La Khe. However, in Dan Hoai there is some evidence that winter–spring rice yields (the main irrigated crop) are lower for farms located at the end of the irrigation system. In Cu Chi, yields for all rice crops were lower for farms at the end of the system, and net returns per hectare from cropping activities highest at the top of the system.

Introduction

This paper explains the techniques of gross margins analysis. They are used to assess the income generating activities of households in three irrigation systems in Vietnam. This analysis can also be used to simulate the changes water supply may have on users. The importance of different elements of the farming system can be isolated, and the significance of individual costs and returns can be identified. The attractiveness of the approach is that it allows for a comparison to be made between households, as they are standardised according to a common unit, usually by area. Water volumes could also be used as a standardising unit, but only in cases where it is objectively and precisely measured.

This approach can be used to answer a set of related questions. The correct questions to ask can be derived from hypothesising how the system operates, then, by utilising the output from the gross margins analysis, assessing whether they have an influence or not. Of particular interest in the studies presented in this paper is the impact that water availability has on crop production and farm income. Chien (2001) argues that it is generally accepted that farmers near the irrigation headworks have ready access to water, but farmers further

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down the system complain that water delivery is less timely and that water is sometimes insufficient to meet crop needs. Hence, where farmers derive their incomes from and how reliant they are on crops that are water dependent is of interest. In addition, the price paid for water and its relation to total farm output and costs is of interest. In order to undertake this analysis, it is necessary to compare farmers with different water availability located within each irrigation scheme. In other words, the issues of importance assessed in this study do not involve a comparison of farmers located in different irrigation systems. Rather, of interest are the differences that occur between farmers located in the same irrigation system, yet who have different access to irrigation water because of their location in relation to main water distribution canals.

The Technique of Gross Margins Analysis

Gross margins analysis is a well-known technique that can be used to assess the economic and financial elements of a farming system, and to measure the likely effect any change that is proposed to that system. The technique is well grounded in economic theory and has been used to analyse a wide range of issues, under many different circumstances. An assessment of improvements in the technical efficiency of water delivery in irrigation may have a great impact on farmers. To understand the impacts these changes have on the economic circumstances of farmers requires information obtained from a gross margins analysis of farms in the regions in question.

The gross margin for any enterprise is the gross income from the enterprise less the variable costs over a specified time period, standardised for differences in a common resource (Sullivan 1987). The 'gross income' is the return a farmer receives for their endeavours, or the price received per unit multiplied by the quantity produced. The 'variable costs' are those directly attributable to the production in question, and include the costs of fertiliser, pesticides, herbicides, seed etc. They do not include fixed costs, or overheads, such as motor vehicle purchase costs, taxes etc. Variable costs vary with the level of output, while fixed costs are incurred regardless of the quantity produced. The 'period' under investigation is usually a year, but could be a

season or the life of a project. Gross margins are standardised to a common resource, like land, in order to allow comparisons to be made between different enterprises. There is nothing to stop analysts from standardising against any common resource. For instance, it might be prudent to standardise according to the quantity of water used per farm. The only requirement is that the unit of standardisation has to be measured objectively and accurately. In less-developed countries, this cannot be done for water use.

Obst et al. (1999) argue that gross margins analysis can be used to identify many different factors about a farming system. Consequently, it can be used to answer a set of questions, not just those related to the question at hand; so much so that a gross margin is usually assessed as a first stage in any economic analysis. It is used to diagnose any weaknesses of the existing business and to prescribe actions needed to reorganise it (Rickards and McConnell 1967). Its role in assessing change management is highlighted in Makeham and Malcolm (1993) and Malcolm et al. (1996). In a diagnostic sense, technical and economic efficiency is measured by comparing the gross margins of all existing activities on the farm. Also, a set of standards can be developed for a number of farms within a region, in order to make comparisons between them.

If a relatively low gross margin is identified, then closer examination is warranted and the following symptoms looked for:
• high input costs relative to output prices
• low output associated with low variable costs, indicating inadequate inputs
• excessive expenditure relative to the value of output
• unsuitable production techniques.

If inefficiencies are identified and corrected, the farm household should increase net farm income.

With respect to irrigation farmers in Vietnam, it is important to find out whether profitability is affected by the cost of water, its use and availability, the practices employed by different farmers and their strategies towards a range of practices.

It should be noted that a gross margins analysis has a number of deficiencies. Most importantly, it can be difficult to distinguish and attribute costs to particular enterprises. It is also assumed that, if a regional or aggregate analysis is attempted, any farmers chosen for the analysis are representative of all farms in the region. Finally, any changes suggested from the

analysis are assumed to be independent of the fixed cost involved. To overcome these deficiencies, a number of assumptions are usually made. Analysts who make these assumptions and those who use particular studies should review and question each assumption with a view to assessing its applicability.

Farming Systems in Vietnam

A precursor to undertaking a gross margins analysis is to come to terms with the farming system used in the region. A farming system is the activities that farmers use to produce output. In a gross margins analysis it is necessary to assume that the farming system is somewhat common to all farms assessed. While each farmer may have an individual approach, to a great extent their activities are determined by the agro-climatic conditions that prevail. In addition, the provision of irrigation leads to the proliferation of a monoculture. In the case of Vietnam, that monoculture is the production of rice. The purpose in this section is to describe the farming system in Vietnam. This analysis provides the basis upon which a gross margins analysis can be undertaken.

The farming systems in Vietnam are explained in detail in the first paper in these proceedings (Malano et al. 2004). The farming system in the major river deltas of Vietnam would appear to have two basic parts to it (see Figure 1). The first is a cropping enterprise that is water and land constrained. The cropping enterprise is based mainly on rice production, supplemented to a very limited extent with other crops. The production of rice is used to sustain life. Consequently, while some households sell rice, in many households much of what is produced is consumed domestically. The livestock system would appear to be a commercial operation. Farmers sell livestock to earn the money required to buy the necessities of life not produced on farm. In Vietnam, as workers' incomes rise, the demand for meat is also increasing, resulting in good returns for farmers. Yet, the ability of farmers to produce more livestock is both time and capital constrained. Water is used in the cropping sub-system and not in the livestock sub-system. One interesting issue that may arise is that, if improvements are made to the supply of water to farmers, they may not invest further resources in rice. Rather, they may shift these resources into the livestock operation, where it is believed there is some money to be earned.

A characteristic of Vietnamese agriculture is the scale of the enterprises and the system of governance that constrains them. Many households farm less than a hectare, which is often spread over several unconsolidated plots. Farmers' land exists in different parts of the commune, on different fields of varying quality. While not collectivised, farmers are not completely free to produce any product they believe would be profitable. Some restrictions on land use, especially for wet rice land, are specified on Land Use Right Certificates, and government policy to ensure food security and regional rice production is still important (Marsh and MacAulay 2002).
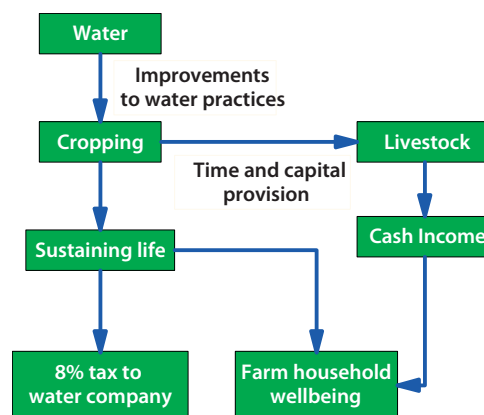
Figure 1. The water–farm economy in Vietnam

Farmers in the north pay a fixed fee for water, based on the yield of their crop. The fee is capped at approximately 8% of the yield. Part of this fee is paid to the irrigation management company (IMC), and part to the local cooperative, which is responsible for maintenance and management at the tertiary canal level. The exact fee, expressed as a quantity of rice per hectare, is determined at provincial level, based on a five-year moving average of rice yield for the province. So, while a farmer may have a yield that is different to that determined by the commune, the amount paid in fees is determined at the aggregate level. The water fee is actually paid in Vietnamese Dong (VND), and the price of rice used to determine the fees is set at provincial level, and can be varied according to seasonal conditions and market prices. In general, the price is always less than the market price. In addition, the water fee

can be varied if the farm household is a member of a priority group, such as a war veteran.

In the south, the provincial governments also set water fees. In Ho Chi Minh City Province, where Cu Chi is located, the water fee has remained unchanged at 300 kg of rice per ha per year for the past decade, regardless of whether or not farmers make use of the water. The fee is paid in VND, with the rice valued by the provincial government. The IMC representative visits each farmer with a member of the local water users association, to collect the fee.

Several questions arise from this brief view of the irrigated farming system in Vietnam. It could be asked, as water availability differs within each irrigation scheme what happens to the:

• yield of various rice crops?
• crop incomes as the seasons change?
• relative importance of income from dry crop production?
• water fees paid per hectare?
• total farm income and household income levels?
• percentage of total net income earned from cropping activities?

Answers to these questions help explain the system under investigation and assist in understanding the importance of irrigation water to farmers in the system.

Data

Attempts to improve the efficiency of publicly managed irrigation schemes in Vietnam are undertaken within a framework that the suggested improvements will have a beneficial impact on the users of water, i.e. farmers. The purpose in this paper is to investigate the impacts that the supply of irrigation water has on farmers. To that end, a gross margins analysis of representative farms in three different irrigation schemes is undertaken. The aim is to assess whether farm profitability was affected by variability in the supply of irrigation water due to location within the system, and the cost of that water.

Collecting the data needed to undertake a gross margins analysis suffers from all the problems associated with collecting any data, and has a few more of its own. Those extra problems relate to the separation of fixed and variable costs, and the ability to attribute individual costs to individual activities. At a more general level, any data collection method must balance the need for representativeness and completeness with the costs of acquiring it. Completeness requires that farmers be surveyed in great detail on information that at times requires recall rather than documentation. Representativeness requires that sufficient farmers are surveyed in order to quantify the diversity of the enterprises in question.

The farmers in the three irrigation systems, two in the north and one in the south, were surveyed as part of a wider project (ITC 2001). It must be asked: how is it known that the surveyed farmers are representative of others in the system? While it is difficult to ascertain representativeness between systems, it would appear that surveying farmers along canals is a reasonable sampling process, as water availability is of major concern in this study. Thus, farm households from the top, middle and end of canals in each scheme, with households at the end of canals perceived as having poorer access to irrigation water, can be compared.

In northern Vietnam, two surveys of farmers in the La Khe and Dan Hoai irrigation systems were undertaken. Both schemes are located in the Red River Delta, 25 km southwest of Hanoi. The La Khe System is approximately 8600 ha, while Dan Hoai is nearly 8000 ha, of which 6800 ha are irrigated in any season. The La Khe scheme supports 20,000 people. In Dan Hoai, there are 39 communes with a population of 329,000. At La Khe, 40 farm households were surveyed, while in Dan Hoai 30 were surveyed. In the south, 30 households were surveyed in Cu Chi. The Cu Chi irrigation scheme covers an area of 8500 ha. Farmers are organised into one of 82 water users' associations, which is in addition to their normal connection to a commune.

The household survey conducted in Cu Chi was very different to those conducted in Dan Hoai and La Khe. This is partially a result of differences in the personnel conducting the survey and in the farming system that operates in the south of Vietnam. The Cu Chi survey data have more demographic detail and less on the costs of production, than those conducted in the north. Despite this, the data collected from Cu Chi were analysed in a manner consistent with the analysis of the data obtained at La Khe and Dan Hoai, albeit that different assumptions need to be invoked when each gross margins analysis is undertaken.

Assumptions

In undertaking the analysis of farm households it was necessary to make the following assumptions:

- Spring, summer and winter dry crops are treated in an aggregate way. The income derived from the production of each crop on farm is summed and divided by the area planted to these crops. Consequently, no gross margins are provided for individual dry crops. This assumption was employed, as a breakdown of the costs of producing individual dry crops was not known. This assumption has no real bearing on the analysis at hand, as the dry crops are, by definition, not irrigated.

- Livestock income per hectare is derived from the sale of all livestock and divided by the total farm area. Consequently, like the case of the dry crops, and for the same reasons, livestock income is an aggregate figure that has no bearing on the water assessments conducted in this analysis. It should be noted that the use of the total farm area in this case is possibly not ideal, as many livestock are grazed off-farm and certainly not on areas that are cropped, although crops may be grown for livestock feed.

- Total income reported in the analysis refers to the income derived from farm activities and not from any other income-generating activities. Total household income includes the activities from all income-generating operations.

- It was necessary to impute a price of all fertilisers used on the farm, as many farmers made use of manure. So the price of fertilisers equals the total money spent on fertilisers, divided by the total quantity used (including manure).

- Unlike the rice crop, the labour used on dry crops was not disaggregated according to the season in which the crop was grown. What was known was the amount of labour needed to produce a hectare of a particular dry crop. These data were used to determine the quantity of labour used in each season to produce dry crops. The assumption underlying this approach is that, regardless of the season, the same quantity of labour is required to produce a given dry crop.

- While many data were collected on costs that could be attributed to particular crops (especially those that are irrigated), several costs could not be attributed to an individual activity. These unattributed costs include the costs of pesticides and herbicides, labour rents, the water and protection fees, agricultural taxes and water-maintenance fees. These need to be handled in a whole-farm budgeting approach, but are divided by the area serviced by irrigation on each farm.

- Data on the quantities of pesticides used were calculated on a per-farm basis. Information exists on nine different types of pesticides used and the application rates were determined from scientific and input supplier sources. The price of each type of pesticide was obtained and multiplied by the application rate to derive a cost per hectare.

- It was noted from the surveyed data that some farmers provided voluntary labour to the IMC. This labour is a cost to the farmer and was calculated by taking the number of days worked voluntarily and multiplying by the going wage rate (US$0.66/day).

Results from Dan Hoai

Staff from the Vietnam Institute of Water Resources Research carried out a survey at six communes in two districts of Hoai Duc and Dan Phuong in September 2000. The households surveyed included farms located at three different parts of the system, considered as upper, middle and lower parts of the Dan Hoai service area. From anecdotal evidence, it is believed that those at the top of the scheme have the best access to water, while those in the middle have better access than those at the end. Thirty households were surveyed in detail and 27 provided sufficient data for analysis. The survey determined actual incomes from farm activities (income from cultivated crops and livestock), cash and labour costs incurred for farm activities, off-farm and trade activities, and perceptions of irrigation and drainage service.

A number of general results can be derived from a cursory glance at the survey responses. These include that the average household landholding in Dan Hoai is 0.19 ha (or 5.33 sao[1]). All but one of the 30 households had net positive returns (from all income-generating activities), They ranged from US$153 to US$3400. Taken overall, it is correct to say that the surveyed households show, not unexpectedly, a great deal of diversity in activities and income. Further analysis of the data was undertaken, taking into account the location of the household in the irrigation system. These results are presented in Table 1.

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[1] A sao is a common unit of land area in north Vietnam. 1 sao = 360 m^2; 27.8 sao = 1 ha.

The concomitant effects of changes in rice yields by location and fairly uniform prices, result in gross and net returns varying in accordance with the yield. However, difference between locations and crops seems more pronounced than it was for the yields. In fact, crop expenses are lower for farms at the top of the system than those at the middle and end, and this accentuates the yield difference into a greater net income difference. Expenses for spring rice (seed, fertiliser and labour only) are US$296/ha at the top, US$364/ha in the middle, and US$343/ha at the end of the system. Expenses for summer rice (seed, fer-

tiliser and labour only) are US$281/ha at the top, US$358/ha in the middle, and US$337/ha at the end of the system.

The water fee paid per hectare is highest at the top of the scheme and lowest at the end of the canal, but the difference is small – US$8/ha. Differences in water fees are caused by the amount of land in each area that is gravity, part-gravity or non-gravity irrigated. The water fee is not high, averaging only US$70/ha. This represents only 2.6% of total farm costs, and 3.3% of the average gross returns from all cropping activities.

Table 1. Results of gross margins analysis of Dan Hoai irrigation system data – selected averages

Item	Units	Top (n=7)	Middle (n=5)	End (n=15)	All farms (n=27)
Farm size	m^2	2,120	2,160	1,866	1,987
Yield spring rice	kg/ha	6,847	6,115	6,255	6,383
Yield summer rice	kg/ha	6,032	5,468	5,845	5,824
Gross crop income per ha					
Spring rice	US$	927	813	840	860
Summer rice	US$	807	727	780	780
Spring dry crops	US$	287	193	0	107
Summer dry crops	US$	47	153	0	47
Winter crops	US$	540	493	127	300
Net crop income[a] per ha					
Spring rice	US$	633	453	493	520
Summer rice	US$	527	373	447	453
Spring dry crops	US$	140	107	0	53
Summer dry crops	US$	13	80	0	13
Winter crops	US$	293	233	60	153
Net livestock income per ha	US$	313	720	973	753
Total gross farm income per ha	US$	3,733	3,887	4,513	4,193
Net farm income					
total	US$	237	357	262	273
per hectare	US$	1,107	1,373	1,460	1,353
Total net household income	US$	791	432	262	273
Of which: Percentage income from cropping		26	35	18	23
Percentage income from livestock		7	47	26	22
Percentage income from other		66	18	56	55
Water fees per ha	US$	75	74	67	70
As: Percentage of gross cropping income		3.0	3.0	3.9	3.3
Percentage of total farm costs		3.0	2.7	2.4	2.6

[a] Net crop incomes are net only of costs that were able to be differentiated between crops; hence there will be a discrepancy between these and the latter figure in the table 'Net farm income/ha', which is net of all farm costs.

Net farm income per hectare is lowest for farms at the top of the canal. This can be shown to be attributable to livestock activities. Net cropping income is US$792/ha at the top of the system, US$655/ha in the middle of the system, and US$486/ha at the end of the system. This is possibly the strongest indication from the data that cropping activities are favoured at farm locations nearer to the irrigation headworks.

Only relatively small percentages of total net income are derived from cropping activities. They range from 18% at the end of the system, to 35% and 26% at the middle and top of the system. The interrelationship between cropping activities, livestock activities and off-farm income in these small-farm households is complex. Thus, it is difficult to assess the effect of water availability on farm activities and farm income from farm production data. Furthermore, cropping activities are related to subsistence needs, whereas income from livestock and off-farm activities are used to create cash income.

Results from La Khe

Forty households in the La Khe irrigation system, from communes located at the top, middle and end of the N5 secondary canal, were surveyed in 2000. Data from all but two households were used in the analysis. The data for La Khe are more detailed than those for Dan Hoai and, as a consequence, all but one of the costs could be attributed to individual activities. In this sample, no farmer grew dry crops during the spring and summer production periods; all dry crops were produced in winter. The average household landholding was 0.30 ha (8.42 sao). Households, on average, had net positive returns from agriculture of US$316 (range US$64–794) and net household incomes of US$379 (range US$113–1460). Analysis of the data, based on location in the system, is shown in Table 2.

Spring and summer rice produced at the top and middle of the scheme returned approximately US$267/ha and US$327/ha, respectively, per rice crop, net of expenses; while at the end of the canal, returns are considerably higher at US$413/ha for the spring crop and US$367/ha for the summer crop. The differences between the gross and net margins, i.e. the costs of producing each crop, tend to accentuate the effect of yield differences on farm returns. In other words, production is more expensive at the top of the canal where yields are lower, than at the end of the canal where yields are higher.

The water fee per hectare is highest at the top of the scheme and lowest at the end of the canal. Again, this would be related to the type of irrigation service provided: gravity, part-gravity or non-gravity. The fee averages around US$67 per ha. This represents, on average, 7.6% of the costs of production per farm. Yet, in terms of the gross returns from cropping, the fee represents on average only 5.3%. As this cost is not dissimilar to the set charges for water, the results of the water component of this analysis are considered to be reliable.

Total net farm income and farm income per hectare are highest at the end of the system. There is little difference in the performance of farm incomes in the middle and top of the system. Average net household income (which included income generated off-farm) is similar at all locations: around US$1307/ha at the top of the system, US$1227/ha in the middle, and US$1260/ha at the end of the canal.

The percentage of net household income derived from cropping, livestock and other activities is shown in Table 2. In this sample of farms from La Khe, the percentage of total net income derived from cropping activities was high at all locations, ranging from 47% at the top of the system to 55% and 70% at the middle and end of the system. By and large, it could be said that these farmers rely on rice production for a major component of their income.

Results from Cu Chi

Forty-four farm households located at the top, middle and end of the Cu Chi irrigation system were surveyed in 2000 by staff from the Southern Institute of Water Resources. In Cu Chi, the average household landholding is 0.61 ha. Net returns from agriculture ranged from an average of US$1230 for farms located at the top of the scheme, to US$571 for farms located in the middle of the system and US$822 for farms located at the end of the scheme. An analysis of the data was undertaken, taking into account the location of the household in the irrigation system. The results obtained are detailed in Table 3.

Gross returns for individual crops tend to follow the same trend as the yield for each crop across both the location of the farm and the season in which the crop is grown. This occurs because price for rice, both spatially and temporally, is fairly uniform. Figures for gross returns in Table 3 do not always show this, as these average gross returns include all surveyed farms, whereas not all farms grow each

crop; for example, monsoon long and short-season varieties are mutually exclusive. Overall, more income per hectare is made from cropping activities at the top of the canal. Gross and net income per hectare from all crops is around 40% less for farms located at the middle or end of the system, compared with farms located at the top of the system.

The water fee per hectare is highest at the top of the scheme and lowest at the end of the canal. The fee averages only US$4/ha over all the sampled farms. This represents approximately 3% of the costs of production per hectare. Yet, in terms of the returns from rice (i.e. the gross returns), the fee represents only approximately 2%. This cost would appear to be significantly lower than those reported to be charged to water users. However, in a assessment of company viability (reported in Davidson et al. (2004)) it was found that, on average, only $US12/ha was paid in water fees by users across the system. This difference is believed to be due to the problems the IMC has in collecting water fees in selected areas.

Net farm income per hectare was lowest for farms in the middle of the scheme and considerably higher, by nearly US$1627/ha, at the top of the scheme. Much of this difference was caused by differences in net cropping returns per hectare: at the top of the scheme these were US$1840/ha, compared with around US$933/ha at both the middle and end of the system. This is possibly the strongest indication from the data that farming activities were favoured at farm locations nearer the irrigation headworks. Total net household income was US$1805 at the top of the system, only US$1121 in the middle, and US$1384 at the end of the system.

Table 2. Results of gross margins analysis of La Khe irrigation system data – selected averages

Item	Units	Top (n=13)	Middle (n=11)	End (n=14)	All farms (n=38)
Farm size	m^2	2,570	3,584	3,047	3,039
Yield					
Spring rice	kg/ha	4,231	4,583	4,826	4,552
Summer rice	kg/ha	4,038	4,199	4,380	4,211
Gross crop income per ha					
Spring rice	US$	540	560	633	580
Summer rice	US$	507	513	580	533
Winter crops	US$	113	60	247	147
Net crop income per ha					
Spring rice	US$	267	333	413	340
Summer rice	US$	267	320	367	320
Winter crops	US$	93	33	120	87
Net livestock income per ha	US$	400	247	287	313
Total gross farm income per ha	US$	2,040	1,673	1,993	1,913
Net farm income					
total	US$	227	323	357	316
per hectare	US$	1,020	933	1,187	1,053
Total net household income	US$	330	432	382	379
Of which: Percentage income from cropping		47	55	70	58
Percentage income from livestock		34	20	24	25
Percentage income from other		19	25	7	17
Water fees per ha	US$	73.6	69.2	50.7	63.9
As: Percentage of gross cropping income		6.8	6.2	3.6	5.3
Percentage of total farm costs		7.6	9.5	6.3	7.6

The percentage of net household income derived from cropping, livestock and other activities is shown in Table 3. As expected, given the differences in household income as related to cropping income outlined in the previous section, cropping income was only a relatively small proportion of total household income. Income from livestock and other activities accounts for around 70% of household income (82% for farms at the end of the system).

Conclusions

It can be concluded that a wide diversity exists between and within each system. While the provision of irrigation supplies defines each system and makes it possible, it is difficult to assess from the data whether differences in water provision affected the economic outcome of each farm. Variability in water availability, as assessed by location within the system, appeared to have little effect on the yields and incomes of farmers in La Khe. In Dan Hoai, there was some evidence that winter–spring rice yields (the main irrigated crop) were lower for farms located at the end of the irrigation system. In Cu Chi, yields for all rice crops were lower for farms at the end of the system, and net returns per hectare from cropping activities highest at the top of the system. It should be remembered that many factors other than water availability affect crop yields and this study does not account for other factors that might influence yield variability.

Table 3. Results of gross margins analysis of Cu Chi irrigation system data – selected averages

Item	Units	Top (n=21)	Middle (n=14)	End (n=9)	All farms (n=44)
Farm size	m^2	5,048	6,577	7,611	6,059
Yield					
Winter–spring rice	kg/ha	3,694	3,417	3,111	3,472
Summer–autumn rice	kg/ha	3,472	3,028	3,222	3,278
Monsoon short-season rice	kg/ha	3,893	3,611	2,944	3,667
Monsoon long-season rice	kg/ha	4,139	2,972	2,750	3,222
Gross crop income per ha					
Winter–spring rice	US$	307	380	253	320
Summer–autumn rice	US$	360	313	113	293
Monsoon short-season rice	US$	307	207	113	233
Monsoon long-season rice	US$	140	180	260	173
Dry crops	US$	727	60	413	453
Gross livestock income per ha	US$	1,680	447	1,160	1,180
Total gross farm income per ha	US$	3,520	1,587	2,313	2,660
Net farm income					
Total per farm	US$	1,230	571	822	937
per hectare	US$	2,647	1,020	1,693	1,933
Total net household income	US$	1,805	1,121	1,384	1,501
Of which: Percentage income from cropping		29	34	19	28
Percentage income from livestock		39	17	41	34
Percentage income from other		32	49	41	38
Water fees per ha	US$	24.5	25	19	24
As: Percentage of gross cropping income		2.9	4.5	3.1	3.3
Percentage of total farm costs		1.4	2.2	1.7	1.6

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Asset Management Modelling for Infrastructure Management in Vietnamese Irrigation Management Companies

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Abstract

An adaptive asset-management framework and geographical information system software were designed to assist in the task of managing the infrastructure by the irrigation management companies in Vietnam. The aim of the approach is to calculate how much companies will need to replace the infrastructure under different renewal strategies. The software tool can be used to maintain an up-to-date database of asset condition and to carry out various financial calculations and modelling including depreciation and condition-based renewal costs. This approach was applied in two irrigation systems in Vietnam. The costs were assessed of three different renewal strategies, one assessing a linear depreciation, another involving a full annuity and the final approach taking a partial annuity. It was found that, for the Cu Chi system, full renewal cost varies between US$41.00/ha and US$28.00/ha when the interest rate varies between 3% and 9%. The equivalent renewal cost for the Dan Hoai system varies between US$33.00/ha and US$22.50/ha.

Introduction

The condition and adequacy of the infrastructure in an irrigation scheme play a critical role in the ability of the scheme to deliver a specified irrigation service. In many developed countries, including Vietnam, the irrigation and drainage infrastructure is less than well-managed due to low maintenance expenditure and insufficient provisions for renewal of assets. The poor condition of the assets, combined with shortcomings in the design criteria, also imposes some limitations in the implementation of improved operational procedures.

The management and operation of irrigation and drainage infrastructure involves a number of events including planning and constructing new assets, maintenance and rehabilitation, and the modernisation of assets to meet new service requirements. An asset management program takes account of all these events. Hofwegen and Malano (1997) defined asset management programs as 'A plan for creation or acquisition, maintenance, operation, replacement, modernization and disposal of irrigation and drainage assets to provide agreed level of service in the most cost effective and sustainable manner'. The various processes involved in asset-management

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planning for the provision of an irrigation and drainage service include (Figure 1) an:

- analysis of irrigation delivery service specifications
- assessment of current condition and performance
- estimation of the investment required in future
- assessment of the maintenance expenditure
- analysis of the sources of future renewal requirements
- estimation of the water fee to be collected.

The aim of this paper is to present a framework and a set of tools that can be used by managers to develop strategies suitable for renewing assets in the long-run. This process starts by carrying out an inventory of the existing asset base. It also covers asset renewal costs to determine the overall cost of providing irrigation and drainage services. The asset-management framework was applied to two irrigation schemes: the Dan Hoai system in the Red River Delta (RRD) and the Cu Chi system in southern Vietnam.
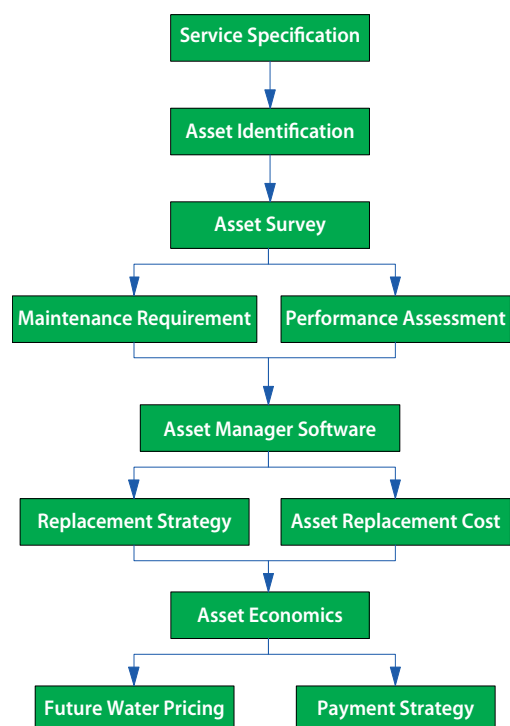

Figure 1. Steps involved in an asset management program

Asset Data Collection

A major component of asset-management planning is the assessment of the extent, function, condition, value and performance of the individual assets (Burton et al. 2003). This is carried out by surveying the irrigation and drainage assets according to a specific condition rating. An asset survey, which is carried out using a global positioning system (GPS) based system, can be used to provide the data required for the development of a geographical information system (GIS) based database of asset condition and performance (Malano et al. 2004).

The main elements of the asset survey are:

1. preparation of base maps by digitising remotely sensed imagery
2. preparation of data-entry forms for asset survey using Map Pad[TM]
3. identification of assets to be surveyed, and preliminary training of irrigation management company (IMC) staff
4. asset survey for the main canal and its structures, followed by similar survey of secondary canals
5. preliminary analysis of the asset database, followed by entry of other attribute data needed for the calculation of annuity.

The data-collection system used for the asset survey had three main components (Figure 2):

- a differential global positioning system (DGPS) to locate and geo-reference assets
- a hand-held computer (HPC) to store the gathered information
- a desktop PC to upload the information.

Previously prepared GIS base maps for asset survey are transferred to a hand-held computer after pre-processing using a GIS software. Electronic data-entry forms prepared using Map Pad™ software[1] are directly interfaced with the DGPS device which runs on the hand-held computer. The Map Pad data collection forms are designed to provide explicit menu-driven options from which the data collector must choose. Additional asset data may be added later as they become available. Geographical information about the asset (i.e. identification, lati-

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[1] Map Pad™ is no longer commercially available and has become the ESRI product 'ARCPAD'; the full functionality of Map Pad, including the ability to customise data forms, is available in version 6.0 accompanied by 'ARCPAD Builder'. The software runs on PC and HPCs, but requires the Windows Pocket PC operating system.

tude and longitude coordinates) and data-entry forms can be displayed for on-the-spot recording by the operator. The data collected during field survey are listed in Table 1 and the criteria used for the survey of asset condition are given in Table 2. Maintenance and repair requirements at the time of the survey were also recorded to enable an estimate of the maintenance backlog for the entire system.

Asset Management Modelling

Modelling framework

The main outcome of an asset-management program is a comprehensive investment program to achieve a sustainable level of service provision. The approach taken for the calculation of infrastructure cost is based on the following:

- asset condition rating based on its ability to perform its function and overall decay

- ascribing asset importance and calculation of overall condition rating
- estimation of residual life based on condition
- estimation of asset replacement cost and annuity based on residual life.

The asset condition rating is carried out on the basis of two parameters: condition, and hydraulic performance (Tran et al. 2003). Asset condition refers to the ability of the asset to perform the function for which it was intended. The condition of assets is the result of several factors, including wear and tear, quality of maintenance, age and quality of construction, and is a key measure necessary to determine the residual life of assets. Hydraulic performance refers to the ability of the asset to satisfy the function for which it was designed. A scoring system is usually applied to rate the performance of assets. The criteria used to evaluate the hydraulic performance of assets in this model are described in Table 3.

DGPS LOGGER + Aerial
Receives signals and notes x,y,z position.

24.224

HAND-HELD PC + 8 Mb memory
- displays base map of area to be surveyed (ARCVIEW shape file)
- displays form to enter survey data and store it in database.

DESKTOP COMPUTER
· Receives survey data as shape file
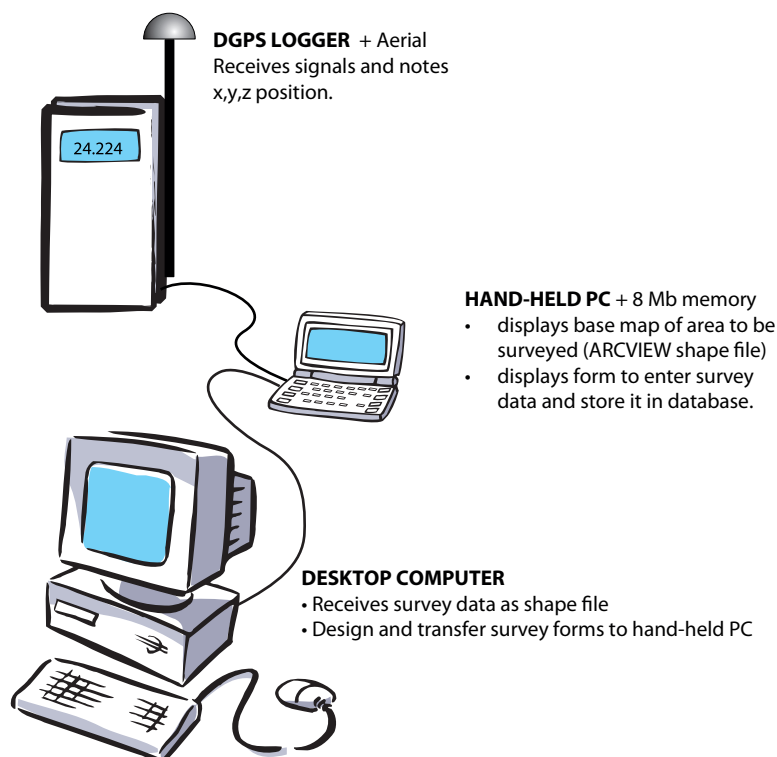· Design and transfer survey forms to hand-held PC

Figure 2. Integrated asset survey and software system

Assets have a different number of individual components that may lead to asset failure. In the proposed model, the importance of each component is weighted on a scale of 0 to 1.0, with the final condition rating resulting from the composite weighting of all components as shown in the following equation:

$$A = \sum_{i=1}^{z} a_i w_i \tag{1}$$

where

a_i = component condition rating

w_i = component weighting

A = overall asset condition rating

Z = number of rated components.

The condition of each asset is used to calculate the residual life of the infrastructure on the basis of the overall rate of decay experienced during the life of the scheme. The main assumption involved in this approach is that the same level of maintenance will be applied in future.

In this model, the rate of decay of assets is described by a continuous function of asset age of the following form:

$$A = br^{\ln(t^*)} \tag{2}$$

where A = overall condition rating;

b = lowest condition rating (highest condition rating = 1);

t^* = dimensionless time ($e^{\frac{\ln\left(\frac{1}{b}\right)}{\ln(r)}} < t < 1$); and

r = decay factor.

Table 1. Description of asset details surveyed

Canal details	Canal structures	Other structures (bridges, culverts etc.)
Canal name	Structure name	Structure name
Canal ID	Structure ID	Structure ID
Cross section details	Location (longitude and latitude)	Location (longitude and latitude)
Canal capacity condition	Gate condition	Structural condition
Outer side slope condition	Structural condition	Discharge condition
Lining condition	Staff gauge condition	
	Lifting mechanism	

Table 2. Asset survey criteria

Performance grade	Description	Criteria
1	Good	Recently constructed, rehabilitated or repaired
2	Fair	Some wear and tear, small cracks, hydraulically operation is not affected
3	Poor	Significant structural cracking, needs major structural repairs, frequently fails to achieve required standards
4	Very poor	Severe structural cracking, structural collapse, not at all in working condition and needs major repair or replacement

Table 3. Criteria for assessing asset hydraulic performance

Rating	Criteria
1	No constraint to pass maximum required discharge
2	Discharge capacity <10% below maximum required at full supply level
3	Discharge capacity between 10% and 20% below maximum required at full supply level
4	Discharge capacity >20% below maximum required at full supply level

This rating function takes into account the decay pattern appropriate for each asset, such as accelerated decay or delayed decay. The decay curve also reflects the level of expenditure needed to bring the asset to its original condition. Assets with a faster rate of initial decay require greater investment to upgrade their condition earlier in their lives than assets with a more uniform rate of decay. The asset decay factor also has an effect on decisions about future strategies (on whether to maintain, replace, rehabilitate, or upgrade) that result from their present condition.

Asset replacement costs are then calculated after accounting the inflation rate for the residual life as follows:

$$RV = P \times (1 + IF)^{RL} \qquad (3)$$

where

RV = asset replacement value

RL = residual life of the asset

IF = inflation rate

P = present value of asset replacement.

To account for the full cost of providing irrigation and drainage services in perpetuity it is essential to use a renewals-accounting process that ensures adequate funding for the renewal of assets when needed. This entails setting up a renewal fund that ensures sufficient capitalisation over the renewal planning period so the management company can invest in asset replacement, rehabilitation or modernisation. The calculation of this annuity is based on the current rate of interest earned by fixed-term deposits.

Three alternative forms of annuity calculations available in the software are (Malano et al. 2004):

• depreciation
• full renewal
• partial renewal.

The calculation of depreciation is based on a linear depreciation model; that is, one where a constant annual rate of depreciation is used. Full renewal annuity assumes that the entire replacement value of the asset will be recovered during the residual life of the current assets. Partial renewal assumes that the residual value of assets will be recovered during the residual life. This approach assumes the remaining value of the asset is written-off or sunk.

The linear depreciation annuity is calculated as:

$$DA = \frac{RV}{n} \qquad (4)$$

where

DA = depreciation annuity

RV = asset replacement value

n = asset life (years).

The full renewal annuity is calculated as:

$$FA = \frac{RV \times i}{(1 + i)^{RL} - 1} \qquad (5)$$

where

FA = full renewal annuity

RV = asset replacement value

i = interest rate

RL = residual life of the asset.

The partial annuity is calculated as:

$$PA = \frac{RE \times i}{(1 + i)^{RL} - 1} \qquad (6)$$

where

PA = partial financial annuity

RE = residual value of the asset.

The residual (written-down) value is calculated as:

$$RE = RV - D \qquad (7)$$

where

RE = residual value of the asset

D = depreciation

RV = asset replacement value.

The calculation is based on current asset condition. The asset condition is used to determine the actual residual life of the structure. The approach taken for the calculation of infrastructure cost is based on the use of conditions based depreciation (CBD), which ascribes an estimated residual life to each asset according to its current condition (Malano et al. 2004).

Asset Manager software

A GIS-based software, called Asset Manager, has been designed for storing, manipulating and retrieving asset data (Malano et al. 2004). The software has three components: a graphical user interface (GUI) built on Visual Basic, a modelling component and a GIS-based database management system (Figure 3). The model has special features to

search and update asset information resulting from condition changes due to maintenance or other events. The software can be used to tally asset condition and calculate asset investment in the future and asset financial annuities. The results can be graphically displayed or exported into an Excel™ spreadsheet for further analysis.

The software is designed so that a similar interface can be replicated and adapted to other systems with minimal changes.

The main inputs needed for the calculation are:
- *asset database* which consists of asset details, location, asset condition rating, replacement cost and year of construction
- *asset parameters* which includes asset ratings, decay factor and asset life
- *canal cost* which includes unit excavation and lining cost for canals
- *financial parameters* based on interest rate and inflation rate.

Results and Discussion

Asset Manager was used to develop an asset-management plan for the Cu Chi and Dan Hoai irrigation systems in Vietnam. In the following sections, a description of the main elements and outcomes of the asset management for each system are presented.

Cu Chi system

The tally of asset condition for Cu Chi shows that offtakes, regulators, culverts and drainage orifices are in fair condition, but that some assets are in poor condition and require renewal in the short term. In Cu Chi, 105 assets including offtakes, regulators, culverts and drainage orifices are in condition 2 (fair) and 10 structures are in condition 3 (poor) (Figure 4). The investment profile shows that a large investment is required in the next 10 years as a group of assets (offtakes, regulators, culverts and drainage orifices) will reach the end of their lives (Figure 5). The IMC will need to invest US$0.60 million over the next 10 years to replace assets in poor condition. This translates into high-cost recovery annuities to make provisions for this investment in this period.

Canal excavation cost occurs only once in the life of the asset and is therefore not included in the renewals calculation, although the initial cost must be taken into account. On the other hand, the cost of lining is included in the annuity calculation as it requires future replacement and regular maintenance. The main and secondary canals in Cu Chi have been concrete-lined very recently and therefore the current condition rating is high.

The replacement annuity is most sensitive to the life cycle of each asset and decreases with an
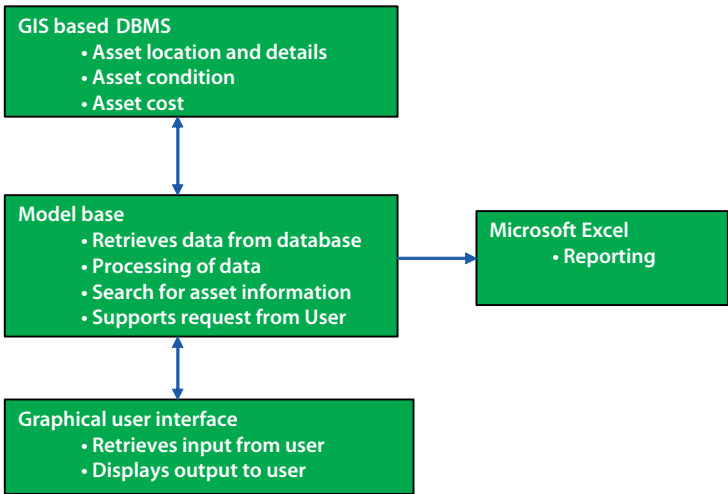

Figure 3. System architecture for Asset Manager software

increase in asset life. Annuities are also very sensitive to prevailing interest and inflation rates. The analysis was undertaken for interest rates varying between 3% and 9%. Full renewal cost varies between US$41.00/ha and US$28.00/ha for this range of interest rates, while partial renewal cost varies between US$21.00/ha and US$14.00/ha. As the interest rate increases, the full and partial annuity decreases as a result of the renewal funds invested by the IMC producing a higher return.

Dan Hoai system

In Dan Hoai, the tally of asset condition shows that 164 assets are in good condition, 53 in fair condition and 11 in poor condition. The IMC needs US$1m in another 15 years to replace its decayed assets. Full renewal cost varies between US$33.00/ha and US$22.50/ha for 3% and 9% interest rates, while partial renewal cost varies between US$16.00/ha and US$11.00/ha. The difference between full renewal and partial renewal annuities
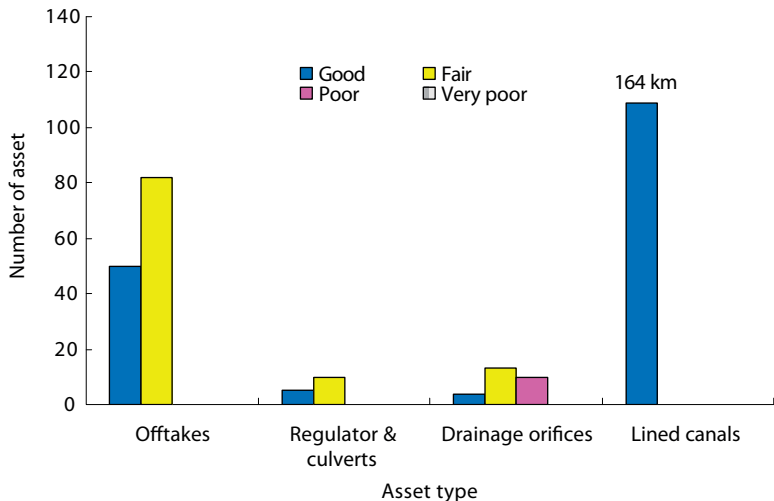

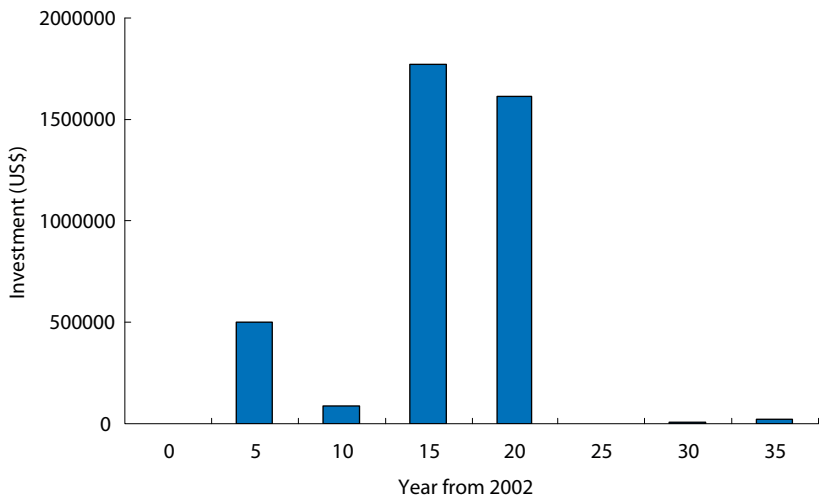**Figure 4.** Tally of asset condition for the Cu Chi irrigation system

Figure 5. Investment profile for asset renewal in the Cu Chi irrigation system

depends on the general condition of assets. In general, the difference between the two approaches is reduced as the condition of the asset base is improved and the residual life of assets approaches the full life of new assets.

Conclusions

Asset-management planning of irrigation and drainage services includes assessing current condition and performance, estimating the investment required in future, assessing the maintenance expenditure and analysing the sources of future funds and estimating the water fee to be collected. The project team developed an integrated information technology system for rapid data collection and management of asset information.

The integrated information technology was used to study the current situation of Cu Chi and Dan Hoai irrigation systems in Vietnam. The investment profile in Cu Chi and Dan Hoai shows that a large investment is required in the next 15 years. Full renewal cost varies between US$41.00/ha and US$28.00/ha in Cu Chi and US$33.00/ha and US$22.50/ha in Dan Hoai at 3% and 9% interest rates.

The implementation of an asset-management program delivers the following benefits:

• the asset-management program enables the management to estimate the actual cost of providing irrigation and drainage services and makes it aware the financial viability of the IMC in the long term

• GPS-based technology used for rapid data collection of irrigation and drainage infrastructure improves the capacity for simultaneous on-site assessment of asset condition

• the GIS-based asset-management software is designed in such a way that the same information can be readily replicated for other projects with minimal changes and can assist the IMC with the task of improving maintenance and sustainability of the infrastructure.

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Assessing the Financial Viability of Irrigation Management Companies: a Case Study at Cu Chi, Vietnam

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Abstract

It has been argued that the provision of water is a service not a good. It could be argued that the providers of those services play the most important role in the whole irrigation sector. For without them, the whole industry would collapse. Because of their importance, or perhaps because of the enormous costs associated with providing the infrastructure they control, many of these companies are publicly owned. Possibly as a consequence of their ownership structure, analysts have legitimately questioned the economic viability and management of these firms. The case is made that many of these companies do not run profitably, that they rely on government subsidies to survive, that they do not spend enough on maintenance and that they run down their capital base.

Introduction

The purpose in this paper is to outline a method which can be used to evaluate the financial viability of irrigation management companies (IMCs). To demonstrate these techniques, the financial viability of a publicly owned IMC located at Cu Chi in Vietnam is used. Of concern and contention in any irrigation scheme is the price that the company should charge for water in order to recover costs in the short run. It was found that the company could not operate without subsidies and did run down its assets. Thus, it was not profitable or viable. It was found that there was a great disparity between what the consumers were charged for water and what the company received for supplying it.

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The Ethics of Running a Publicly Managed Company at a Loss

One of the most often cited claims of the problems associated with running publicly IMCs is their apparent reliance on government subsidies to survive. The clear implication of this claim is that these companies do not collect enough fees from water users (mainly farmers) to cover their costs and, as a consequence, are poorly run. This mismanagement, it is claimed, is having a detrimental effect on the water sector, as markets are distorted, and that if this continues into the future the companies will run down their asset base.

Despite this, it could be argued that public companies should be judged differently from private entities. Their aims, establishment and very existence are different to privately owned companies. It should be asked:

- how does a government entity face bankruptcy when it has vast taxpayer funds behind it?
- if governments set the pricing structure for water supply companies how could a company trade its

way out of perceived difficulties by raising prices?

- are rules governing the raising of investment for a government company very different to those that apply to a privately owned company?

The only option to make the companies viable is to reduce costs, which may mean reducing service levels. Such an option may be unpalatable to a poor country reliant on irrigation to produce meagre food supplies. If a government wishes to run one of its entities at a loss, in order to provide the people with a given return, why shouldn't it? Isn't this in some way similar to a private company operating a 'loss-leader' strategy? A legitimate activity of government is to determine the distribution of resources. If a government made the decision to distribute resources towards farmers and food production and away from other sectors in the economy, all an economist can do is point out the costs and ramifications of that decision, not pass comment on its morality.

However, this is not to say that IMCs could not run more like privately owned companies. Governments may prefer to reduce their subsidies and invest in higher returning assets elsewhere in the economy. The Government of Vietnam has said that in coming years it would wish to reduce and ultimately abolish subsidies for these companies, and would do so on a gradual basis over a number of years (Le Quang Anh, Vietnam Institute for Water Resources Research, Hanoi, pers. comm.). Further, any differences in company ownership should not preclude an analysis of public companies using measures employed by privately owned companies. The measures themselves are readily acceptable procedures that, if applied in an unbiased way, provide valuable information to the government and managers of these companies.

The Classification of Costs: Some Broad Distinctions

Irrigation companies incur a number of costs in providing water services to farmers. Among these costs, a distinction must be made between economic costs and financial (accounting) costs incurred in the provision of irrigation services. Financial costs are the capital, operation and administrative costs involved in ensuring a sustainable provision of irrigation water supply service (Rogers et al. 1997). In

theory, they include those costs incurred by the company and recorded in the accounts of the company. In practice, however, accounting standards vary between countries and depreciation and renewal costs may not be adequately identified. A method to identify asset depreciation costs for irrigation and drainage infrastructure is described by Malano et al. (2004).

A definition of financial costs and economic costs is shown in Figure 1. In addition to financial costs, economic costs include all costs attributable to the company, including externalities which are not normally recorded in the company accounts (Greig 1998). This study is concerned with the identification of the financial costs involved in the provision of irrigation and drainage services by irrigation companies. It is assumed that an economic valuation of economic cost items, such as externalities, is beyond the scope of this study. In the Vietnamese context at least, externalities and the opportunity cost of capital are not accounted for in the sector's economic analysis and become actual costs to society.
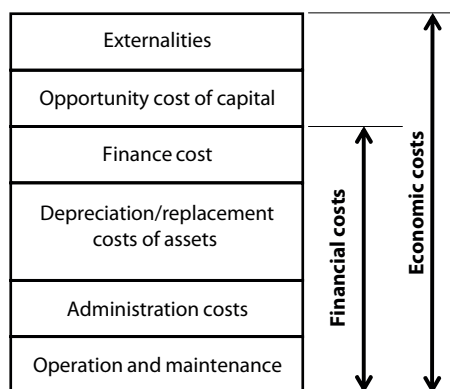

Figure 1. Definition of economic and financial costs

The Procedures Involved in Financial Management

The procedures involved in financial management assessments (hereinafter termed 'the procedure') would appear to follow a path common to many disciplines. It involves first gathering relevant data and knowledge on the circumstances facing the firm in

question, including understanding the firm's aims and core business. Then the appropriate tools are selected, the data are processed, the information is examined and alternative policy recommendations are specified. While each of these tasks might appear to be discrete, in fact, one is dependent on the other.

Perhaps the issue that drives the procedure most is to decide what is wanted from the analysis. The IMCs in Vietnam are principally in the business of regulating the flow of water. While it is easy to think of the core business as selling water, Vietnam is not a country in which that commodity could be said to be scarce. Rather, what is scarce is the service of controlling and managing water. The concerns of IMCs in Vietnam primarily relate to the amount of subsidy received from the government, their inability to raise prices, their need to meet future asset replacement needs and the cost of maintaining the current structure of the business (Chien 2001). In other words, the stresses facing the companies concern liquidity, profitability, and asset management and structure.

The factors that govern the procedure are data availability. In Vietnam, financial information on individual companies is very limited and its reliability subject to varying levels of doubt. Disregarding the question of reliability, or assuming that it is necessary to work with the data that are available, a set of balance sheets was obtained for the Cu Chi IMC. For each, data were collected over a seven-year period, from 1996 to 2002. It should be noted that analysing a seven-year period requires some assessment of the rate of inflation. Reliable estimates of the rate of inflation in Vietnam are available from the IMF (2004). In addition, if the measures are to be expressed in US currency terms, changes in the US dollar–Vietnamese dong exchange rate over the period under investigation need to be accounted for. Data on exchange rates were also derived from the IMF (2004). Data were collected on the income derived from water fees earned from farmers and from other sources. On the outgoings side of the ledger, data were collected on the costs of operating and maintaining the irrigation scheme, the number of staff employed, the salaries paid, any outstanding loan repayments, the amounts paid for water from the reservoir, administration and insurance expenses and tax payments.

There are many variables that could be assessed to gauge the viability of the IMCs. These variables relate to all aspects of the business. The selection of relevant statistics should be governed by industry standards and on the problem at hand. The measures assessed in this study are summarised in Table 1. They can be segregated into revenue, expenditure and performance measures.

Malano and Burton (2001) suggest that average total revenue can be used by a firm to reveal how much it earns for every piece of effort it performs. The higher the figure the better off the IMC would be. In essence, the average revenue is the price received by the IMC. The average total revenue can be calculated by dividing the gross revenue collected by the area serviced (measure 1) or the volume of water delivered (measure 2). According to industry standards, and from a purely theoretical stance, a measure by volume is preferred. After all, it could be argued that the volume of water is the true quantification of the product in question. However, from a pragmatic stance, water is charged on an area basis in Vietnam, as flow data are both scarce and unreliable. Gross revenue includes all sources of income, i.e. water fee revenues, other income and government subsidies. Hence, while measures 1 and 2 reveal the revenue the IMC receives, they are not the prices paid by consumers.

To calculate the consumers' price, the water fee revenue earned by the IMC can be divided by the area serviced (measure 3) or by the volume of water delivered (measure 4). The amount paid by the government for irrigation can be calculated by dividing the subsidy IMC receives by the area serviced (measure 5) and the quantity of water delivered (measure 6).

Expenditure can be assessed in two very different ways. First, at an aggregate level, the total expenditure can be divided by either the area serviced (measure 7) or the quantity of water delivered (measure 8) to yield what it costs the IMC, on average, to produce the product. The lower the company's costs, the more efficient it tends to be, in the short run. As with the revenue measures, the water industry prefers measures by volume, yet pragmatism means that area-serviced measures are more revealing. Second, individual costs can be monitored to observe which components have the greatest influence on the company (measures 9a to 9j). Not only do costs that account for a large proportion of total expenditure need to be identified, but so too do those that change markedly. By assessing individual costs the potential threats selected inputs have on the company's viability can be identified.

The performance measures evaluated in this study were, by and large, taken from Malano and Burton (2001). They are measures of how technically and managerially efficient an IMC is. It has been claimed that, in many irrigation schemes, managers make little attempt to maintain the operation of the scheme.

Hence, the maintenance costs to gross revenue (measure 10) may provide a good indicator of how well a system is maintained. However, interpreting the measure can be difficult. A higher percentage may mean that the managers are dedicated to maintaining the capital base of the scheme. Yet, it may also mean

Table 1. Summary of measures of financial viability

No.	Name	Ratio	Units
Revenue measures			
1	Average total revenue	Gross revenue collected/Area serviced	US$/ha
2		Gross revenue collected/Volume of water delivered	US$/m^3
3	Average water fee revenue	Gross water fee revenue/Area serviced	US$/ha
4		Gross water fee revenue/Volume of water delivered	US$/m^3
5	Average subsidy	Government subsidy/Area serviced	US$/ha
6		Government subsidy/Volume of water delivered	US$/m^3
Expenditure measures			
7	Average total costs	Total expenses/Area serviced	US$/ha
8		Total expenses/Volume of water delivered	US$/m^3
9	Individual costs as a percentage of total expenses		
9a	power electricity	Power costs/total expenses	%
9b	wages and salaries	Wages and salaries/total expenses	%
9c	repairs and maintenance	Repairs and maintenance/total expenses	%
9d	administration	Administration costs/total expenses	%
9e	insurance	Insurance/total expenses	%
9f	payment of loans	Bank loans/total expenses	%
9g	water supply costs	Water supply costs/total expenses	%
9h	water collection fee costs	Water collection costs/total expenses	%
9i	taxes	Taxes/total expenses	%
9j	summation		
Performance measures			
10	Maintenance cost to revenue	Maintenance cost/Gross revenue collected	ratio
11	Cost recovery	Gross revenue collected/Cost of management, operation, maintenance	ratio
12	MOM to area	Cost of management, operation, maintenance/Area serviced	US$/ha
13	Personal cost per employee	Salary costs/Number employed	US$/ha
14	Revenue collection performance	Cost of collection/Gross revenue collected	ratio
15	Revenue collection efficiency	Gross revenue collected/Total leviable fees	ratio
16	Balance, exc. subsidy	(Gross revenue – govt. subsidy – total expenditure)/Area serviced	US$/ha
17	inc. subsidy	(Gross revenue – expenditure)/ Area serviced	US$/ha

that managers may need to spend more, as the capital base has been run down, or that they perform the maintenance tasks less efficiently. If the ratio remains constant over a number of years, then it can be surmised that the capital base has been maintained. However, if it varies greatly, then it could be concluded that the capital base has been run down. By assessing the gross revenue divided by the cost of management, operation and maintenance (measure 11) an idea of the efficiency of the IMC can be gained. The larger the ratio, the more efficient the company is. Efficiency can be improved by either increasing output or thus revenue, or by reducing the inputs, which in turn reduces the costs of operation. The importance of this can be further highlighted by assessing the costs of management, maintenance and operation in comparison with the area serviced (measure 12). This ratio, unlike the previous one (measure 11), compares an indicator of input usage to a constant output. A low or falling ratio reveals an improvement by the company. In a similar vein, some indicator of the salary costs to the number of employees (measure 13) provides a good gauge of the efficiency of labour. This ratio, like measure 10, is difficult to interpret. Some constancy in the measure over a number of years is to be desired. In Vietnam, much anecdotal information has been collected on the inability of IMCs to collect the revenue they are due (Le Quang Anh, Vietnam Institute for Water Resources Research, Hanoi, pers. comm.). A company's performance in this area can be gauged by assessing the cost of collection divided by the revenue collected (measure 14). One might expect that the lower the percentage the more efficient the revenue collection fees are. Revenue collection efficiency (measure 15) measures the ratio of what is actually collected to what could be collected. To determine what could be collected in water fees, the water fees set by the provincial government are multiplied by the area serviced. Finally, it is necessary to assess the IMC's bottom line. This is a ratio of what they earn less total expenses divided by the area serviced. Given that the firms appear to rely on subsidies to survive, two measures of what they earn can be used. The first relies on total gross income (measure 16) and the second relies on gross income less subsidies (measure 17). In both cases, the higher the figure the better off the company is. Yet, they could be negative. In this case, rather than revealing the net income per hectare, what is yielded is the loss per hectare. The figure reveals the net income per hectare earned or lost by the operation.

The Cu Chi Irrigation Management Company

Even though individual firms operate in the same industry, each firm operates under different sets of circumstances and conditions. While the same set of measures can be applied to each firm, and similar recommendations made upon an assessment of the marginal conditions facing each firm, it is impossible to make any significant comparisons between firms. Exercises that attempt to do this, often known as benchmarking studies, are fraught with theoretical and methodological inconsistencies. The purpose in this section is to briefly outline the conditions and circumstances under which the Cu Chi IMC operates.

The Cu Chi IMC supplies water to the Cu Chi irrigation scheme. It is based in Ho Chi Minh City Province and gets its water from the Dau Tieng Dam in Tay Ninh Province. The IMC is required to purchase water from the government in Tay Ninh Province. The scheme is a gravity-fed system of channels that is not reliant on pumping. In 2003 there were 283 people employed, some of them casual employees. To operate the company some staff are located at seven stations throughout the scheme. These stations act as the link between the farmers and the company. The farmers are organised into 82 water users associations all based around either one or two tertiary canals. The company has three functions:

- *Operate the scheme by governing the flow and direction of water*: It does this at each station by measuring the depth of water as a means of calculating the flow in different canals. If the water is determined to be inadequate, the station staff contact head office from where staff ring the reservoir authority and ask for more water.
- *Schedule the water used in the system*: In undertaking this task, station staff meets with the leaders of water user associations to determine future demand.
- *Collect revenues from users*: This task is performed by the station leader who, with a representative of the water users association, visits each farmer and attempts to garner as much of the owed fee as possible.

The provincial government sets water fees. In Ho Chi Minh City Province, the fee is US$20/ha/year. It is calculated according to a formula where each farmer must pay, for each hectare, a cost equivalent

to the value of 135 kg of rice grown in the winter–spring season and 165 kg/ha per year for rice grown in the summer–autumn season. These fees change only according to the price of rice, which is currently set at US$0.066 per kg. The formula has not been varied since its inception. Further, regardless of what is grown, the water fee is calculated according to what it would be if only rice were produced. While the pricing formula is given, it may not reflect the price charged by the company, as a history of fee default exists and not all the area available for cropping is irrigated.

The Financial Viability of the Cu Chi Company

The results of the analysis conducted on the Cu Chi IMC are presented in Table 2. Reliable data from the company's financial balance sheet were obtained from 1996 to 2002. From these data, it was possible to obtain some idea on most of the 17 revenue, expenditure and performance measures.

In nominal terms, the average revenue of the Cu Chi IMC rose from approximately US$20.41/ha in 1996 to US$33.61/ha in 2002. The rise in earnings can be seen in the returns per volume, which rose from US cents $0.04/m^3$ in 1996 to US cents $0.10/m^3$ six years later. The greatest rise occurred in the last year. If the company's earnings from fees levied on its consumers alone are considered, then the revenues for water rose by 128% between 1996 and 2002, to over US$12.32/ha. Marsh et al. (2004) surveyed the fees producers paid for water. They found that farmers paid US$24.00/ha. The difference between the two values possibly reflects the degree to which the company has a bad debt problem and the difficulties associated with collecting water fees. The residual between total earnings and earnings from water fees is made up by government subsidy, which rose by approximately 40% over the period, to US$20.90/ha in 2002.

What can be concluded from this analysis is that, in 2002, the price the company received for its efforts was US$33.61 for every hectare it serviced. The consumers on average paid US$12.32/ha for water services. The government contributed US$20.90 for every hectare serviced, the difference being made up from the sale of other services. These figures reveal the major weakness inherent in the company. That is, that it is totally reliant on govern-

ment subsidies for survival. Over 62% of its revenue came from subsidies. The gap between what the consumers (in this case farmers) pay for water and what the company receives is so large that any withdrawal of the subsidies might force the closure of the operation.

Irrigation management companies that receive subsidies experience all the uncertainties associated with the fear that they may be removed at any time. By receiving a subsidy, the companies face greater risks as their fortunes are now not only subject to the uncertainties that exist in agriculture and in the water markets within which they operate, but are also subject to all the macroeconomic and cross-sectorial issues facing the government. The efficient management of people and processes is at the centre of economic growth. IMCs that have efficient management structures make money. Finally, of crucial concern to IMCs is asset management, as they tend to be decreasing cost industries. Their very existence is dependent on the investment that has been made in the infrastructure. A failure to look after assets will result in the demise of the company.

In 1996, the Cu Chi IMC needed US$22.78/ha to service its clients. These costs rose to US$38.22/ha in 2002, an increase of nearly 68%. Total expenditure rose greatly at the end of the period and yet was somewhat stable during the early and middle years at between US$0.05 and US$0.08 for every m^3 delivered. Not once between 1996 and 2002 did the Cu Chi IMC's revenues (which included earnings from all sources) meet its expenditure. At an individual cost level, three items account for most of the costs. Two of them (administration and salaries, which account for between 40% and 65% of all costs) can and need to be contained. Further, their contribution to total expenditure is highly unstable. The company's exposure to its other major cost, the cost of water from the reservoir, would appear to be declining. The amount of total expenditure spent on maintenance, between 3% and 8% would appear to be low and volatile. The company needs to contain its costs, particularly those associated with staff, if it is to be considered viable in the long run. Such viability could be threatened if the scheme is not adequately maintained.

In terms of performance, it would appear that the measure of maintenance to revenue (measure 10) is low and erratic over the period under investigation. It varies from a high in 1996 of 23 to a low of only 8 in 2002. Yet the ratio first fell, then rose, before

Table 2. Results of the financial viability assessment of the Cu Chi irrigation management company, Vietnam

No.	Item	Units	1996	1997	1998	1999	2000	2001	2002
	Revenue measures								
	Average total revenue								
1	by area	US$/ha	20.41	28.91	30.44	31.90	31.47	31.15	33.61
2	by volume	US cents/m^3	0.04	0.06	0.06	0.06	0.07	0.07	0.10
	Average water fee revenue								
3	by area	US$/ha	5.40	8.05	10.12	11.87	11.35	10.43	12.32
4	by volume	US cents/m^3	0.01	0.02	0.02	0.02	0.02	0.02	0.04
	Average subsidy								
5	by area	US$/ha	15.02	20.85	18.81	19.31	20.05	20.54	20.90
6	by volume	US cents/m^3	0.03	0.04	0.03	0.04	0.04	0.05	0.06
	Expenditure measures								
	Average total costs								
7	by area	US$/ha	22.78	32.08	34.00	33.20	34.76	35.11	38.22
8	by volume	US cents/m^3	0.05	0.06	0.06	0.06	0.07	0.08	0.12
	Individual costs as a percentage of total expenses								
9a	power electricity	%	0.00	2.89	5.00	2.07	0.00	1.25	1.19
9b	wages and salaries	%	33.77	42.61	42.94	43.62	50.47	54.89	54.09
9c	repairs and maint.	%	5.52	3.51	7.82	7.25	3.65	3.48	2.52
9d	administration	%	10.55	9.30	10.16	10.94	11.15	7.27	9.51
9e	insurance	%	0.00	2.37	3.47	3.90	4.81	6.88	6.94
9f	payment of loans	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9g	water supply costs	%	43.94	29.22	25.05	25.00	20.79	19.72	19.14
9h	water collection costs	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9i	taxes	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9j	summation	%	93.79	89.89	94.45	92.79	90.87	93.49	93.38
	Performance measures								
10	Maintenance to revenue	ratio	23.31	13.98	22.86	19.11	11.13	11.53	7.58
11	Cost recovery	ratio	0.48	0.45	0.56	0.61	0.50	0.46	0.50
12	Management, operation and maintenance to area	US$/ha	11.36	17.77	20.71	20.52	22.69	23.05	25.27
13	Personal cost/employee	US$/ha	229.46	407.59	435.43	431.91	523.28	574.85	616.53
14	Revenue collect/extraction	ratio	na	na	na	na	na	na	na
15	Revenue collect efficiency	ratio	21	23	36	47	56	55	53
	Balance								
16	excluding subsidy	US$/ha	−17.39	−24.02	−22.37	−20.60	−23.35	−24.51	−25.51
17	including subsidy	US$/ha	−2.37	−3.17	−3.55	−1.30	−3.29	−3.96	−4.61
	Notes:								
	Inflation rate (1995 = 100)	index	105.7	109.1	117	121.8	119.7	119.2	123.8
	Inflation adjustment	2002=100	85.38	88.13	94.51	98.38	96.69	96.28	100.00
	Exchange rate	VND:US$1	11038	11683	13268	13943	14168	14725	15280

falling quite significantly. In terms of cost recovery by the Cu Chi IMC, a measure of its efficiency, it would appear that the revenue accounts for only somewhere near half of the expenditure on management, maintenance and operation. Not only that, but the figure is highly erratic, rising to 61% in 1999, before falling back to around 50%. The rises are associated with an improvement in efficiency, while a fall has the opposite effect. The costs of management, maintenance and operations per hectare, and the costs per employee, appear to have risen significantly between 1996 and 2002. Of these two indicators, it would appear that salary costs to employee numbers is nearly out of control, rising nearly 169%. It should be noted that this rise is possibly overstated, as it was calculated on the current employment profile of 285 employees. However, even if it is assumed that half those numbers were employed in 1996, the rise is still sizeable. Finally, while the efficiency of revenue collection is rising, from approximately 21% in 1996 to around 55% in 2001, it is still not adequate (see measure 15). This statistic reveals that, for whatever reason, the IMC in a good year collects only a little more that half the revenue it could obtain if the government's fee structure was applied to the region and was collected.

The Cu Chi IMC runs at a loss. The size of the loss was approximately US$4.61/ha in 2002. During the period under investigation, the company never operated at a profit in any year. This loss is further compounded by the fact that the revenues upon which it is based include a sizeable subsidy. If the subsidy is removed, then the losses increase. In 2002, the Cu Chi IMC's losses would have been nearly US$25.51/ha serviced.

What makes these figures so startling and worrying from a company perspective, is not necessarily their size, but what is excluded from the analysis. The expenditure data make no allowance for capital renewal. Malano et al. (2004) have estimated that cost of renewing the assets would require an additional annuity of between US$33/ha and US$50/ha each year, depending on the degree of maintenance undertaken and the rate of interest. They also highlight the low level of maintenance expenditure by the company, suggesting that assets are decaying at a rapid rate. It is as if the company is using the asset as if it were a non-renewable resource. Once it depreciates and eventually breaks down, it will need to be scraped or rebuilt.

The analysis was entirely based on recurrent costs. The sustainability of the company and system operations, however, depends on the ability to support its recurrent cost and sustain its asset base in perpetuity. From a company perspective, this implies the ability to renew its asset base when the current assets reach the end of their economic life. The expenditure data displayed in Table 2 make no allowance for capital renewal.

The balance sheet was analysed to estimate the cost for different services of the company. The costs of operation of the Cu Chi IMC can be grouped into eight categories:

- asset cost
- power cost for irrigation and drainage
- personnel cost which includes salaries paid to full-time, part-time and casual staff
- repairs and maintenance
- administration
- insurance
- bulk water fee, which includes the fee paid to Dau-Tieng reservoir for obtaining water
- miscellaneous expenses.

The comparison of the total service costs, including the asset replacement annuity for the period 1996 to 2002, is presented in Figure 2. Details of this analysis are presented in a paper by Malano et al. (2004). The full cost of providing irrigation and drainage service at Cu Chi is estimated to be US$75.03/ha during 2002. The analysis revealed that here is a steady increase in the staff salary component in different years, a trend which may continue in the future. There is no difference in bulk water fee in different years. But in future there is a chance that the reservoir may charge a higher price for water which will increase the cost of operation.

Currently, the Cu Chi IMC is charging users only 32% of the actual cost of providing irrigation and drainage service. This will affect the long-term sustainability of the company. Marsh et al. (2004) assessed the economic circumstances of farmers in the Cu Chi irrigation system based on the results of a survey of farmers. They found that, on surveyed farms, the water fees only represented 3.3% of the gross cropping income and 1.6% of total farm cost. Total net farm income (gross income less costs) averaged US$1853.30/ha. Under these circumstances, it may be tempting to raise the level of water fees to close the gap between what farmers pay and what would be required to run the scheme in a viable manner. However, such a policy may have
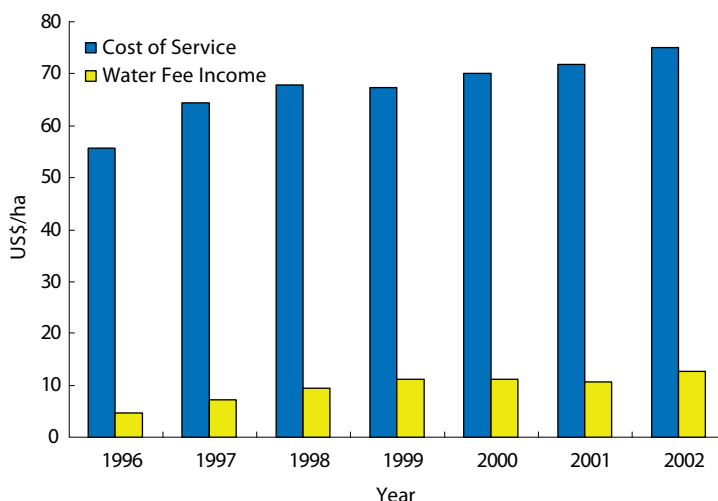
Figure 2. Comparison of renewal-based service cost with water fee income

significant implications for the current cropping system, as the winter–spring and summer–autumn rice crops may not be financially viable. Also, the real economic situation of the farmers needs to be investigated as the landholding is too small in these irrigation schemes.

Conclusions

It was argued that the concerns of IMCs in Vietnam revolved around issues of raising enough revenue to cover costs, their reliance on subsidies from the government and whether they maintain their assets.

It was found in Cu Chi that the IMC should be concerned on a number of fronts. First, it is heavily reliant on government subsidies. Its expenditure was US$4.61/ha above its earnings. If subsidies were removed from the company, it would lose approximately US$25.51/ha. The price paid by consumers is only US$12.32 /ha, relatively small in comparison to the expenditure needed to operate, manage and maintain the scheme. Further, the company has a number of costs that would appear to be out of control. The degree to which maintenance is carried out must also be questioned.

Perhaps of greatest concern is the issue of paying for maintenance and asset renewal. Letting assets run down threatens the long-run viability of the company. Given the amount of capital that is required to regulate water flows, asset renewal and replacement

is an issue that needs to be addressed. While it was not within the scope of this study to assess these long-run issues, it should be noted that the company does not have a strategy for collecting and quarantining funds for this purpose. If it did, then the operating expenses and the costs of running the scheme would be considerably higher.

The full cost of providing an irrigation and drainage service at Cu Chi was estimated to be US$75.03/ha during 2002. The analysis also showed that there has been a steady increase in staff salaries in different years, a trend which may continue in the future.

Currently, the Cu Chi IMC is charging users only 32% of the actual cost of providing an irrigation and drainage service. This will affect the long-term sustainability of the company.

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Assessing Institutional and Pricing Arrangements in Order to Improve Water-Use Efficiency and Viability

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Abstract

To run an irrigation management company requires more than an eye to the costs and services provided. One must also operate in a legal and institutional framework. In most countries, legislation exists to control how the water industry can operate and what it can charge. These laws will affect how each scheme operates. In much of the developing world, water supplies are not measured objectively. As a consequence, area-based charging is undertaken rather than the much preferred volumetric charging. Area-based charging requires a large administrative framework if it is to be effective, a structure that has a number of deficiencies. What is proposed in this paper is a method of moving towards a system of partial volumetric charging.

Introduction

The purpose in this paper is to come to terms with the importance of understanding that institutional arrangements can play a critical role determining the outcomes of the operation of an irrigation scheme. The problem with undertaking this task is that the institutional arrangements under which each scheme operates are different. As a consequence, the best way to demonstrate the importance of institutional arrangements is through an example. The example chosen is how to implement volumetric pricing into a scheme that has area-based pricing. This was a problem faced by the managers of the La Khe irrigation scheme in Vietnam.

It has been argued that volumetric pricing for water would improve the efficiency of irrigation water delivery over the area-based pricing system currently in place in many countries around the world. Many of the arguments put forward in favour of volumetric charging ignore the institutional reforms that would be needed to implement such a change. In this paper, a process is suggested by which a volumetric charge, albeit a partial one, could be implemented. It is argued that water users associations (WUAs) should evolve over a long period to represent farmers' interests. These organisations would buy and pay for water from a water-supply company on a volumetric basis, and distribute it to farmers who would pay for it on an area basis. Using the example of the La Khe irrigation scheme, it was found that, if the changes were implemented, farmers had the potential to reduce the amount they spent on water. However, existing institutional arrangements prevent these reforms from being undertaken at present.

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How to Evaluate Changes in Institutional Structures

Any change, be it a technical one or a management revolution, needs to be monitored. It must be asked: upon what basis would any changes in management and pricing be considered successful? It would seem that significant improvement in four areas would be the most important indicators:

- the distribution and reliability of water provided to farmers
- water fee collection rates
- the operation and maintenance of the scheme, both within the secondary canals where WUAs govern and over the scheme as a whole
- the social standing, incomes and status of farmers.

Of course, the overriding criterion that must govern all change is whether or not it is actually implemented. Without implementation, evaluation of these other issues is superfluous.

Measuring and monitoring the evolution of the proposals, over a significant period, will determine whether the reforms have been successful. If it transpires that the proposals are not ideal, and do not result in the expected benefits, then they can be abandoned. If the evolution is handled slowly, then the costs of not meeting these targets will be minimised.

Existing and Proposed Management Structures

In order to change any institutional system, it is first necessary to be able to describe both the existing and proposed procedures. In addition, it is essential to have a strategy for moving from the existing arrangements to the proposed ones. These tasks are examined in this section of the paper.

An overview of the existing and proposed management and pricing structures is presented in Figure 1. The way water is currently ordered and distributed into secondary canals within irrigation schemes is a problem. The traditional approach in La Khe has been for water-management groups within each cooperative/commune to assess farmers' seasonal water requirements and submit these to the La Khe irrigation management company (IMC). The IMC would deliver water into the appropriate secondary canal, from where it is then distributed to different fields. The IMC bills each cooperative/commune for water used according to an area-based formula which incorporates a differential fee schedule according to whether or not water can be delivered to fields by gravity. The IMC pays the cooperatives and/or communes to collect the water fees from each farmer. Thus, a rather complex billing arrangement exists.

This management arrangement works reasonably well if there is only one cooperative on a secondary canal. The problem in La Khe is that, in general, secondary canals can be used to service two, and sometimes up to four, cooperatives. There has been a tendency for a 'first come-first served' rule to operate. So farmers in cooperatives near the head of the secondary canals get most of the water, to the detriment of those downstream. Further, cooperatives/communes sharing access to the same secondary canals have generally operated independently of one another, especially in respect to both water ordering and in resolving issues of common concern, such as identification of canal maintenance needs.

In order to resolve these inherent problems, it is necessary to change the structures that manage irrigation water and the methods of pricing it (see Figure 1). Water users associations need to be empowered to represent farmers and should not be hindered by other concerns that might arise at a commune/cooperative level. Empowering WUAs to undertake these tasks involves a two stage procedure. In the initial phase, water user advisory committees (WUAC) would be established. This two-stage procedure would occur over a three to four-year period in order to allow all those involved in the process to adjust slowly. These groups need to be based around secondary canals and would take over the water-scheduling and fee-collecting tasks from the cooperatives/communes. They would buy water from the IMC and would charge individual farmers. Further, any disputes amongst farmers would be raised and resolved within the WUA, rather than in some cases between different cooperatives/communes.

Water Pricing Arrangements

The second element of the process is the need to reform water-pricing arrangements. Water is currently sold according to the area of crop to be serviced, and the amount is discounted where water cannot be delivered under full gravity feed. On
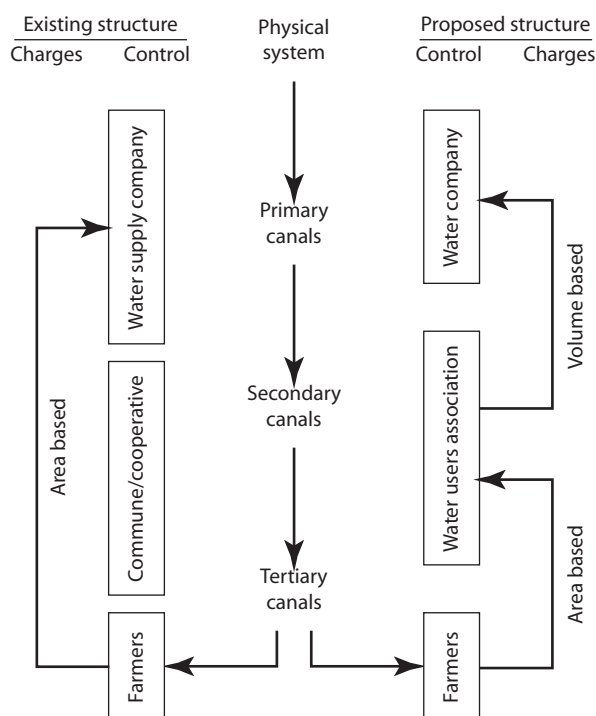
Existing structure
Charges Control

Physical system

Proposed structure
Control Charges

Water supply company

Area based

Commune/cooperative

Farmers

Primary canals

Secondary canals

Tertiary canals

Water company

Volume based

Water users association

Area based

Farmers

Figure 1. An overview of the existing and proposed structures for the supply of water in the La Khe irrigation scheme, Vietnam

average, each farm in La Khe comprises 6.7 sao of gravity-fed irrigation, 2.3 sao of partial-gravity irrigation, and 4.9 sao of non-gravity irrigation.[1] Under the current management structure and water monitoring arrangements, this is the most practical way to sell water. Because the price charged is not related to the volume sold, it is considered that where farmers have access to adequate water supplies, they have no incentive to use it sparingly.

It is proposed that water should be charged according to a two-part formula to be levied initially on the WUAs and then passed on by the WUAs to the farmers. The initial part of the fee is based on the volume sold, while the other part passed on to farmers is based on the area serviced. The total volume of water sold to the WUA could be recorded and used to calculate the variable part of the water costs (such as the electricity used for pumping irri-

gation water). This could be called the 'volumetric fee'. The area of land that can be irrigated from each secondary canal can be used to calculate the fixed part of the water supply costs (such as maintenance and administration costs), and for ease of explanation could be called the 'area fee'.

Thus, it is in the interests of the WUAs to buy the smallest quantity of water possible, just enough to supply its needs, as it is buying and paying for water on a volumetric basis. It is also in its interests to distribute it equitably, as farmer members pay for water on an area basis.

The Performance of the Changes

In La Khe, it would appear that any move towards implementing these changes has failed to materialise after the WUACs were established before the WUAs. The reason for this failure would appear to lie in a misunderstanding of the existing power

arrangements amongst cooperatives/communes. McGrath (2003) argued that collective control over agricultural production in Vietnam eroded in the late-1970s and the early 1980s, to a much larger extent than envisaged or desired by the Government of Vietnam. Villagers and local cadres tended to resist central directives that conflicted with their own interests. They often colluded to circumvent state regulations. In the north of Vietnam, during the 1990s, collectives retained a stronger influence over production than envisaged by national policy makers. In the south, by contrast, most collectives were disbanded and alternative institutional arrangements established. Given that the extent to which policies can be implemented depends on how networks of power are organised, it is necessary to determine what happened at the local level. McGrath (2003) argues '… that whether policies were or were not applied was in large part determined by the relationship between Party and village power structures … traditional kinship and patron–protégé relations deeply embodied in Vietnamese culture and society continued to influence relations between peasant farmers and state authorities'.

Conclusions

It is argued that, in order to get any efficiency in water use, it is necessary to price so that any charge is based on the quantity used. To make these charges possible, a number of changes need to be made to the management structures associated with water. However, the process of implementing volumetric prices in Vietnam is at least difficult, due to institutional shortcomings, if not impossible due to the nature of irrigated agriculture. What results from this paper is a process by which the correct institutional arrangements could be put in place in advance of a funding formula that allows for limited volumetric pricing. The pricing formula works on the WUAs buying water on a volumetric basis and charging farmers on an area basis. Such an approach may lead to significant water savings, as it is in the interest of WUAs to buy as little water as possible and thus pass on the savings to producers.

The problem with the approach is that it fundamentally changes the existing balance of power in the cooperatives/communes. Any change in the balance of power, especially in favour of farmers, diminishes those currently in power. Attempts to implement these changes in La Khe during the late 1990s met considerable resistance. The trials eventually failed well short of reaching any mature stage. Implementation of these arrangements will require some fundamental changes in philosophy among farmers, irrigation system administrators and government agencies.

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