Optimal Multi-Criteria Irrigation Water Management

Ounla Sivanpheng

A dissertation submitted in partial fulfillment of the requirements for

the degree of Doctor of Philosophy in Civil Engineering

at Mahasarakham University

October 2012

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The examining committee has unanimously approved this dissertation, submitted by Mr. Ounla sivanpheng, as a partial fulfillment of the requirements for the degree of Doctor of Philosophy in Civil Engineering at Mahasarakham University.

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ACKNOWLEDGEMENTS

The dissertation would not have been accomplished if without the help from several people. First of all, I would like to thank Assoc. Prof. Dr. Anongrit Kangrang and Mrs. Sudarat Compliew for their invaluable help and constant encouragement throughout the course of this research. In addition, I would like to express the deepest appreciation to my committee Asst. Prof. Dr. Sahalaph Homwuttiwong Dr. Alongkorn Lamom and Assoc. Prof. Dr. Sanguan Patamatamkul for suggestions and all their help.

I would like also to thank the authority of Nam Houm Irrigation Scheme, Naxaythong district, Vientiane capital, Lao PDR for their research data being very supportive.

Finally, I most gratefully acknowledge my family for all their support throughout the period of this research.

Ounla Sivanpheng

ชื่อเรื่อง การจัดการน้ำเพื่อการชลประทานที่เหมาะสมแบบหลายหลักเกณฑ์
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บทคัดย่อ

การจัดสรรทรัพยากรที่มีอยู่อย่างจำกัดเป็นหนึ่งในปัญหาหลักทางด้านการจัดการทรัพยากรน้ำ โดยเฉพาะเมื่อมีการกำหนดปริมาณทรัพยากรต่างๆ ที่จะนำไปใช้ประโยชน์ได้ เช่น ปริมาณน้ำ ขนาดที่ดิน และแรงงาน แล้ววางแผนการใช้ปริมาณทรัพยากรดังกล่าว เพื่อที่จะหาสัดส่วนของพื้นที่เพาะ ปลูกพืชแต่ละชนิด (Crop Pattern Ratio) เพื่อให้ได้ผลตอบแทนรวมสูงสุด วัตถุประสงค์ของการศึกษานี้เพื่อที่จะประยุกต์ใช้แบบจำลองเจเนติกแอลกอริทึม ด้วยค่าประสิทธิภาพการชลประทานแบบแปร เปลี่ยนสำหรับหารูปแบบการเพาะปลูกที่เหมาะสม และ นำรูปแบบการเพาะปลูกที่ได้ไปเปรียบเทียบกับรูปแบบการเพาะปลูกเดิมที่ได้จากแบบจำลองเชิงเส้น

แบบจำลองที่พัฒนาขึ้นนี้ ได้นำไปประยุกต์ใช้หารูปแบบการเพาะปลูกที่เหมาะสมในฤดูแล้ง (เดือนพฤศจิกายน – เดือนเมษายน) ของโครงการชลประทานน้ำฮุม เมืองนาซายทอง นครหลวงเวียงจันทร์ ประเทศลาว โดยมีวัตถุประสงค์เพื่อค้นหารูปแบบการเพาะปลูกที่ทำให้เกิดผลตอบแทนสูงสุดของโครงการ ฟังก์ชันเงื่อนไขของทรัพยากรที่นำไปจัดสรรและใช้ในการค้นหาคำตอบประกอบด้วย สมการการไหลต่อเนื่อง ขนาดพื้นที่ของโครงการ ปริมาณน้ำในอ่างเก็บน้ำ ปริมาณน้ำที่สามารถนำไปใช้ได้ การมีส่วนร่วมในการจัดการน้ำของเกษตรกร ราคาผลผลิตของพืชที่เพาะปลูก การระเหย การซึม และปริมาณฝนในพื้นที่สำหรับหาค่าประสิทธภาพการชลประทาน ใช้แบบแปรเปลี่ยนได้

ผลการศึกษาพบว่า แบบจำลองเจเนติกแอลกอริทึมแบบค่าประสิทธิภาพการชลประทานที่แปรเปลี่ยนได้ที่พัฒนาขึ้น สามารถนำไปหารูปแบบการเพาะปลูกที่เหมาะสมที่ให้ค่าผลตอบแทนสูงสุดได้ เมื่อนำรูปแบบการเพาะปลูกที่ได้ไปเปรียบเทียบกับรูปแบบการเพาะปลูกเดิมที่ได้จากแบบจำลองเชิงเส้น พบว่ามีค่าใกล้เคียงกันมาก นอกจากนี้ยังสรุปได้ว่าแบบจำลองที่เสนอสามารถนำไปหารูปแบบการเพาะปลูกสำหรับโครงการชลประทานอื่นในประเทศลาวได้

คำสำคัญ : รูปแบบการเพาะปลูก, แบบจำลอง แบบจำลองเชิงเส้น, เจเนติกแอลกอริทึม, การวางแผนการชลประทาน, ประสิทธิภาพการชลประทานที่แปรเปลี่ยน

TITLE	Optimal Multi-Criteria Irrigation Water Management
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DEGREE	Ph.D. **MAJOR** Civil Engineering
UNIVERSITY	Mahasarakham University **DATE** 2012

ABSTRACT

Allocation of limited available resources is one of the main problems in water resources management. A Water resource linking issue of system infrastructures, environmental change, water allocation, assessment of water requirement, flow measurement and responsibility of stakeholders. In particular, given the total available resources, for example; water, soil, land area, and manpower, one would like to know what proportion of the available resources should be given for each considered crop ratio in an irrigation project in order to maximize the total profit of agricultural activities. The objective of the study is to find an optimal crop pattern ratio using the Genetic Algorithm (GA) for irrigation planning of the irrigation project, with varying irrigation efficiency from the Mathematical model and farmer participation on water management from analyzing the stakeholders involved in water resources management were then compared with the existing crop patterns of the Linear Programming (LP) model.

The proposed GA model has applied to find the optimal crop pattern ratio in dry-season (November-April) of the Nam Houm irrigation scheme in Vientiane capital, Lao PDR. The maximum benefit of the project was used as the objective function for finding the optimal crop pattern. Constraints functions with continuity equation, available land area, available water resource, farmer participation in water resources management and cost of products were used in GA model. The project water management appraisal was conducted including stakeholders involved in water management in the project. The records of seasonal flow from the reservoir, requested and actual implementation of irrigation area, crop water requirements, evaporation, percolation, and effective rainfall, varying irrigation efficiency, crop coefficient, cropping pattern and crop calendar were used for this illustrative application.

The results have shown that the proposed GA can provide the optimal crop pattern with the maximum benefit. The obtained patterns of the irrigation project were then compared with the existing crop patterns of the Linear Programming (LP) model. The crop patterns from both techniques were in good agreement. Furthermore, the obtained crop pattern can be utilized for efficient planning of irrigation system in Lao PDR.

Keywords : Stakeholders, water resources management, crop pattern, linear programming, genetic algorithm, irrigation planning, varied irrigation efficiency

Contents

PAGE

List of Tables

List of Figures

Figures **Pages**

Figures **Pages**

Chapter 1

Preface

1.1 Background

The Lao People' s Democratic Republic (Lao PDR) is very rich in natural resources, especially water resources. Around 80% of the country's area lies within the Mekong River Basin. The remaining 20% drains through Viet Nam directly to the South China Sea. The major tributaries of the Mekong all have significant watersheds (MRCS Report, 2006).

Nowadays, water resource becomes more and more scarce in many regions of Lao PDR due to increasing demand, and the water needed by agricultural irrigation cannot be increased anymore, so how to allocate the limited water supply effectively over different stages of crop growth, and how to control the quantity precisely for the maximum return from crop become the focus of development of irrigation water management.

The issue of development objectives for irrigation is a prime importance in regards to improving the irrigation road map and development policy, and in determining the respective roles of stakeholders in regards to upkeep and maintenance.

Currently, the government has been trying to adopt Irrigation Management Transfer (IMT) policy nationwide for all the irrigation schemes to transfer to ownership as well as associated cost to beneficiary farmers to reduce subsidies of irrigation sector from the government. However, the processes have not been made smoothly and yet successful because there are a lot of challenges, and issues still remaining. These problems include poor and deterioration of existing irrigation, lacking of farmers' incentive due to low income from rice cultivation caused by uncertainty and unavailability of market particularly in the rural area, and cropping intensity in the dry season under irrigation is still low. In order words, farmers are not willing to grow rice in dry season and these affects to the serious issue in cost recovery. The government, therefore, currently is working on rehabilitation of existing facilities appareling with strengthening of Water User Association (WUA) to recover and upgrade their function before IMT is materialized. But Communities are not able to manage assets sustainably. Irrigation schemes are not well maintained and water user organization is very weak. Operations costs such as electricity are not paid in full by the majority of users resulting in large debts nationally to Electricite du Laos (EdL). Scheme infrastructure depreciates rapidly with the lack of maintenance and repair resulting in investment intensive rehabilitation cycles of usually less than 10 years. Village development funds (VDF) have in general failed to contribute to irrigation maintenance and development and IMT has not improved system sustainability.

It seems that, the issue of the above objectives for irrigation water management is a prime importance. In consequence, an irrigation scheme under poor irrigation planning is the one of the classical problems in water resources management. In particular, given the total available resources such as water, land area, production cost, one would like to know a cropping pattern of the irrigation project in order maximize the total profit. On the one hand, before starting of each irrigation season, an Operation and Maintenance staff of an irrigation scheme should prepare appropriate irrigation planning to ensure that required total of land-area from the farmers for each seasonal cultivation and how much water inflow to the reservoir, and to be distributed into paddy fields. Also the irrigation facilities and structures should monitor time to time. On the other hand, a water resources linking issue of concern, such as: system infrastructures, environmental change, water allocation, assessment of water requirement, flow measurement and responsibility of stakeholders.

Probably, there are many alternative portions for seeking the best way for solving the above challenges such as managing of water resource systems in term of supply management and demand management. In the way of water supply management is to increase water volume by improving storage, renovating a weir or doing excavation of the channel or rehabilitation of water delivery systems, but it may high investment and the local authority has a limited budget for implementation. In another way is demand management that considers improving the efficiency of the system but also to improve the existing system.

The review and analysis of different participatory irrigation management to reflect the essentials differences between: the old land, new land and mega project could be differences in the level of participation, stakeholders, and financial sources and mechanisms (Alansi *et.al.*, 2009). Stakeholders need to participate in water management to effectively integrate the goals of efficiency, sustainability and equity a broad cross section (Alarcon *et al.*, 2006). Supporting stakeholders in managing their water resources to make choice and to reach a common understanding on the necessary arrangements for sharing and allocating water-related goods and service is the basis on which stakeholders have to seek a well-informed decision (Arnold *et al.*, 1998).

In several of case studies are not full comprehensive, in that they cannot represent every activities which needs to be in a stakeholder participation strategy. However, they do represent a broad cross section of some of the issues and challenges.

Improving this situation is to enhance farming technology through training and extension and improving water resources management. The efficient solution points are including strengthening of WUGs through intensive education and involvement of membership improves financial transparency and strict implementation of roles, rules and regulations (RRR). To resolve poor condition of irrigation facilities are repair of irrigation canals and structures, strict implementation of the RRR and increase of repair funds through better Irrigation Service Fees (ISF) collection.

But, often, most irrigation projects lacked satisfactory tools for finding the optimum crop water requirement for each crop pattern. The crop yield is usually affected by crop water requirement and physical soil type which suitable for cultivation of each crop (Zhang, *et al.*, 2008 : 121-132).

In the general theory, there are some techniques developed to improve the effectively irrigation management such as Linear Programming (LP), Dynamic Programming (DP) and Genetic Algorithm (GA) etc.

A Linear Programming (LP) is an optimization technique which widely used to allocate the limited water resources because of the proportionate characteristic of allocation problem. One of the most popular application of the technique in the water resources literature is to find an optimal seasonal crop pattern subjected to limit available resources i.e., land area, water, manpower and cost. In addition, constant irrigation efficiency is used in the constraint LP model.

Most previous study considered the maximum profit subjected to limit available resources, cost of product, constant irrigation efficiency, but there are many factors for sustainable irrigation development such land area constraints, farmer's participation in irrigation management, a varied irrigation efficiency.

The maximization benefit was set as the objective function based on the resources constraints. The constraint functions are linear equation for finding optimum crop pattern when given available water (Kangrang and Chaleeraktrakoon, 2007 : 339-345), (Reine S.R. and Shannon, 1995 : 52-58). A different portion of treated water from wastewater treatment and ground water is included into the water constraints of LP model (Ortega J. F. *et al.*, 2000). A different portion price of irrigation water is considered in constraints of LP model (Cai, McKinney, and Lasdon, 2001 : 667-676). The disadvantage of this model, that is not suitable for heterogeneous soil types due to the constraint function are linear equation but some data input are nonlinear and the efficiency used for this model is constant value. In addition, the previous study did not concern multi-criteria irrigation water management.

Also the dynamic programming was used in water resource management such as using dynamic programming to find infinite stochastic process and a discrete deterministic of the hydrology, land area allocation problems (Richar, 2000 : 503-515), but it is not suitable for these problems.

The other statistical tests is mathematical model which focus on a comparison of two factors - yet most questions we want to examine in the irrigation management involve the influence of many factors. For example, a Fuzzy set is mathematical theory for describing the interested variables from uncertain factors or variables like seasonal inflows and the participation of stakeholder in water resource management. The Fuzzy set model was used to find the irrigation efficiency which corresponding seasonal inflow and farmer participation in water resource management (Kangrang, and Chaleeraktrakoon, 2007 : 339-345)

The GAs, as a kind of new global optimization search method, has many remarkable characteristics. They are computationally simple, adaptive and robust optimization techniques. GAs are based on the principles of population genetics and, constitute a special class among adaptive algorithms. They combine the adaptive process in nature with functional optimizations by simulating the selection of the best performing individuals in the populations. GAs are the iterative search method of "survival and detection" and start with an initial random population, then allocate initial solution to regions of the encoding search space. Among them, three main operators of GAs are selection, crossover, and mutation. Key content of GAs includes parameter encoding, the initial population settings, design of fitness function, penalty function, design of genetic operating and control parameters settings (Ulrich Boldenhefer, 2004), (Bhaktikul, *et al*., 2004 : 1-1127). In the water resources management sector, the GA model was used for finding the optimal cropping pattern (Zhang, *et al.*, 2008 : 121-132), and the GA was used for comparative study of optimization techniques for irrigation project planning (Kuo, *et al.*, 2003 : 59-73).

Hence, in this research is considered that the proposed LP model and GA model have applied to find the optimal crop pattern. Constraints include continuity equation, available land area, available water resource, farmer participation multi-criteria decision in water resources management and cost of products were used in GA model.

1.2 Objectives

This thesis aims: 1) to provide the suitable methodology for irrigation planning and can be used for more complex systems involving non-linear optimization for irrigation water management; 2) to determine an optimal crop pattern with maximum profit; 3) to evaluate the proposed model with the actual cropping pattern in wet season and dry season; and 4) to improve an alternative solution point of stakeholders involved on water resources management in the project considering organization chart, responsibility of stakeholders and level of water management.

1.3 Scope of Research

1. The Nam Houm Irrigation Scheme, Vientiane capital Lao PDR as a case study;
2. The Linear Programming and the mathematical modeling were used for comparison with the Genetic Algorithm model;
3. The research was conducted to analyze heterogeneous soil type of land area, limited water resource and varied efficiency of the irrigation system; and
4. A water resource linking issue of system infrastructures, environmental change, water allocation, assessment of water requirement, flow measurement and responsibility of stakeholders in the project.

1.4 Expected Output

1. Provide new technology by using utilized technique genetic algorithm for regression and prediction of the irrigation planning and varied efficiency for an irrigation scheme in the region;
2. Enhance the technique for the local staff of irrigation in term of water resources management, allocation land area in order to heterogonous soil type for suitable cultivation;
3. Determine the efficient solution points for improving farming technology through training, extension, improving water resources management and strengthening responsibility of stakeholders in the project; and
4. The model can be used to discover an optimal cropping pattern for irrigation planning of all schemes in Lao PDR.

Chapter 2

Literature Review and Related Researches

The Optimal Multi-Criteria Irrigation Water Management is needed to study methodology, literature and related research data to carry out the research activities as following:

1. Theory of water resource management
2. Sustainable irrigation development
3. Theory of farmers' participation in water resources managements
4. Optimization techniques
5. Linear programming model
6. Theory of Genetic algorithm model
7. Theory of Multi-Criteria analysis
8. Related researches

2.1 Theory of water resource management

The overall problems

The overall problems of the water resource management are:

a) Resources under pressure

The world's freshwater resources are under increasing pressure. Growth in population, increased economic activity and improved standards of living lead to increased competition for and conflicts over the limited water resource. A combination of social inequity, economic marginalization and lack of poverty alleviation programmes also force people living in extreme poverty to overexploit soil and forestry resources, which often results in negative impacts on water resources. Lack of pollution control measures further degrades water resources.

b) Populations under water stress

The world population has increased by a factor of about three during the 20th century whereas water withdrawals have increased by a factor of about seven. It is estimated that currently one third of the world's population live in countries that experience medium to high water stress. This ratio is expected to grow to two thirds by 2025.

c) The impact of pollution

Pollution of water is inherently connected with human activities. In addition to serving the basic requirement of biotic life and industrial processes, water also acts as a sink and transport mechanism for domestic, agricultural and industrial waste causing pollution. Deteriorating water quality caused by pollution influences water usability downstream, threatens human health and the functioning of aquatic ecosystems so reducing effective availability and increasing competition for water of adequate quality.

d) Water governance crisis

The above problems are aggravated by shortcomings in the management of water. Sectoral approaches to water resources management have dominated and are still prevailing; this leads to the fragmented and uncoordinated development and management of the resource. Moreover, water management is usually left to top-down institutions, the legitimacy and effectiveness of which have increasingly been questioned. Thus, the overall problem is caused both by inefficient governance and increased competition for the finite resource.

The main challenges

The main challenges of water resource management are:

a) Securing water for people

Although most countries give first priority to satisfaction of basic human needs for water, one fifth of the world's population is without access to safe drinking water and half of the population is without access to adequate sanitation. These service deficiencies primarily affect the poorest segments of the population in developing countries. In these countries, water supply and sanitation for urban and rural areas represents one of the most serious challenges in the years ahead.

b) Securing water for food production

Population projections indicate that over the next 25 years food will be required for another 2-3 billion people. Water is increasingly seen as a key constraint on food production, on a par with, if not more crucial than, land scarcity. Irrigated agriculture is already responsible for more than 70% of all water withdrawals (more than 90% of all consumptive use of water). Even with an estimated need for an additional 15-20% of irrigation water over the next 25 years - which is probably on the low side - serious conflicts are likely to arise between water for irrigated agriculture and water for other human and ecosystem uses. Difficulties will be exacerbated if individual water-short countries strive for food self-sufficiency rather than achieving food security through trade; by importing food countries can in effect import water from more generously endowed areas (the concept of "virtual water").

d) Developing other job creating activities

All human activities need water and produce waste, but some of them need more water or pro-duce more waste per job than others. This consideration has to be taken into account in economic development strategies, especially in regions with scarce water resources.

e) Protecting vital ecosystems

Terrestrial ecosystems in the upstream areas of a basin are important for rainwater infiltration, groundwater recharge and river flow regimes. Aquatic ecosystems produce a range of economic benefits, including such products as timber, fuel wood and medicinal plants, and they also provide wildlife habitats and spawning grounds. The ecosystems depend on water flows, seasonality and watertable fluctuations and have water quality as a fundamental determinant. Land and water resources management must ensure that vital ecosystems are maintained and that adverse effects on other natural resources are considered and where possible ameliorated when development and management decisions are made.

f) Dealing with variability of water in time and space

Almost the freshwater available for human used originated from precipitation which varies immensely over time and space. Most tropical and sub-tropical regions of the world are characterized by huge seasonal and annual variations in rainfall, often compounded by erratic short-term variations. Such variability manifoldly increases the demand for infra-structure development and the need to manage water demand and supply. The challenge in managing variability is clearly greatest in the poorest countries with the least financial and human resources to cope with the problem.

g) Managing risks

Variations in water flows and groundwater recharge, whether of climatic origin or due to land mismanagement, can add to drought and flood events, which can have catastrophic effects in terms of large scale loss of human life and damage to economic, social and environmental systems. Water pollution creates another set of risks, affecting human health, economic development and ecosystem functions. Economic risks are also important in water resources management and development due to the often large-scale and long-term character of the investments required. Political instability and change represents yet another important risk factor for water resource management. To date, relatively little attention has been paid to the systematic assessment of risk mitigation costs and benefits across the water use sectors and to the consequent evaluation of various risk trade-off options.

The principles of water resource management

The principles of water resource management are numerous and each has their areas of appropriate application. The Dublin principles are a particularly useful set of such principles. They have been carefully formulated through an international consultative process culminating in the International Conference on Water and the Environment in Dublin, 1992. They aim to promote changes in those concepts and practices which are considered fundamental to improved water resources management. These principles are not static; there is a clear need to update and add specificity to the principles in the light of experience with their interpretation and practical implementation.

a) Principles have universal support

The Dublin principles significantly contributed to the Agenda 21 recommendations (Norman, Uphoff, 2008) adopted at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, 1992. Since then, these principles (referred to as the Dublin-Rio principles) have found universal support amongst the international community as the guiding principles underpinning integrated water resource management. More recently they have been restated and elaborated at major international water conferences in Harare and Paris, 1998, and by the UN Commission on Sustainable Commission (CSD) at its “Rio +5” follow-up meeting in 1998.

b) The four Dublin principles are:

i) Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.

ii) Water development and management should be based on a participatory approach,

iii) Women play a central part in the provision, management and safeguarding of water.

iv) Water has an economic value in all its competing uses and should be recognized as an economic good.

Policy of water resource management in Lao PDR

Lao PDR has a major water resource endowment with significant untapped potential. The major water demands are domestic water demand, irrigation, hydropower and fisheries demands.

Approximately 80 percent of the country drains to the Mekong River and with Lao PDR's annual rainfall averaging 1,600 mm, some 270,000 million m^3 flows annually to the Mekong, supplying 35 percent of its total flow. This figure represents in excess of 54,000 m^3 of water per capita (1998 population) – the annual current demand of 228 m^3/person is only a small fraction of supply (Country Report. 2007). Figure 1 showed the estimated area of inland water resources is 723,500 ha .

The role of protected areas in water resource management is well and widely appreciated and improved protection of upland catchments is a prominent feature of Government of Laos (GoL) policy for a variety of downstream benefits. Non-protect areas are strongly connected with the role of catchment protection because they tend to be forested and are mainly located in upper catchments. This is by no means an exclusive association; however, as many other catchments are nominally protected either at the provincial level or for other reasons, for example, border security. The Government has made significant progress in water resource management at the policy and strategy level. It has enacted the Water Law, prepared a national water sector profile as well as a Water Sector Strategy and Action Plan (WSSAP). The Government has approved the WSSAP. A coordinating body, the Water Resources Coordinating Committee (WRCC) has been established in Science, Technology and Environmental Agency (STEA). Water resource management is divided into two levels: the national and river basin level. At the national level a National Water Resources Plan will be prepared, which will be followed by River Basin Plans.

The Lao National Mekong Committee (LNMC) in coordination with line agencies and provincial authorities will formulate both the national plan and the river basin plans. The government is undertaking the first water basin approach to management in the Nam Ngum catchments, north of Vientiane capital.

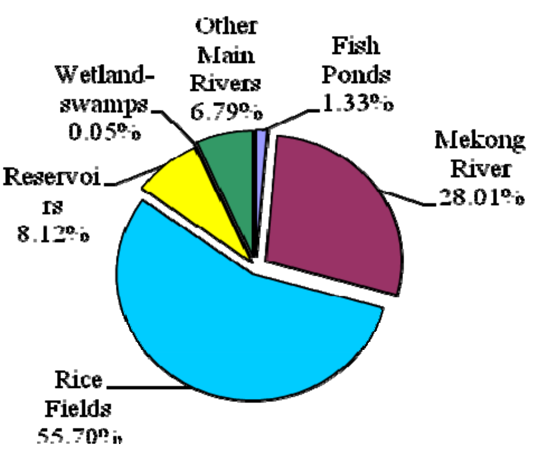


Figure 1 Area of water resources in Lao PDR

Lao PDR is well endowed with water resources and has no expectation of water shortages, except at the local level. Nonetheless, the government is well aware of the need to husband its water resources, as one of the nation's few comparative advantages for economic development. In recent years, GoL has moved significantly to develop its water resource management capacity. The role of protect areas in water resource management is widely appreciated and improved protection of upland catchments is a prominent feature of policy for a variety of downstream benefits especially agriculture and hydropower. Non-protect areas are strongly connected with catchments protection, because they tend to be forested and in the main are located in upper catchments. This is by no means an exclusive association; however, as many other catchments are nominally protected either at the provincial level or for other reasons, for example, border security.

Although there are exceptions, the benefits of watershed protection measures, i.e. a sustained clean water supply, are not acknowledged through investment by water users in management of protected areas. Water supply from protected areas is treated as a free service.

The principal uses for water in Lao PDR are agriculture (especially irrigation), fisheries, industry (power) and drinking water. Subsidiary uses include transport, tourism, education and research. Total water withdrawal is estimated at 1,000 million m^3 per year, less than one percent of the available resource, with the major uses shown in Figure 2 below.

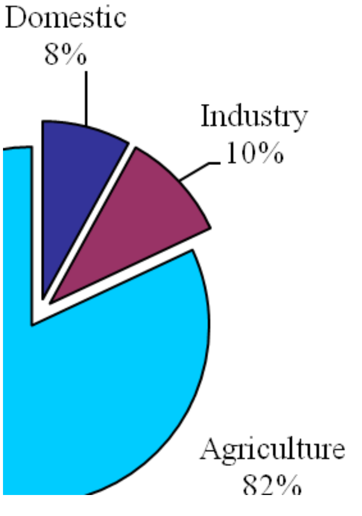


Figure 2 Water withdrawals by sector

About 60 percent of urban areas receive potable water while 40 percent of the rural populations have access to potable water, although only about half of the supply systems actually function. Domestic water charges in urban areas are on a volume basis but the tariff structure fails to cover the direct financial costs of the water supply systems.

2.2 Sustainable irrigation development

Sustainable development involves many things. More appropriate technologies, supportive policies, different ethnics, and changes in individual behavior are among the more obvious factors. One contributing factor that deserves more attention is local institutions and their concomitant local participation.

Institutions such as local governments, user associations or service organization are important for sustainable development in irrigation for a number of reasons:

- For sustainable development, institutions, especially at local levels are important for mobilizing resources and regulating their use with a view to maintaining a long-term base for irrigation management activity;
- Available resources can be put to their most efficient and sustainable use with location-specific knowledge, which is best generated and interpreted locally;
- Monitoring changes in resources' and irrigation systems' status can be quicker and less costly where local people are involved; making adaptive change in resource use is speeded up where local decision-making has become institutionalized;
- While local institutions are always able to resolve irrigation system management conflicts, if there are absent, all conflicts must be dealt with higher levels, yielding slower and often less appropriate outcomes;
- People behavior is conditioned by community norms and consensus, so preserving or instituting practices that are environmentally sound requires more than just individual incentives and persuasion; and
- Institutions encourage people to take a longer-term view by creating common expectations and a basis for cooperation that goes beyond individual interests. To the extent institutions are regarded as legitimate, people comply without (or with fewer) inducements and sanctions.

The sustainable irrigation development is aiming at: to increase rural incomes and stabilize rice availability by expanding irrigated area in both the wet and dry season, and to improve the operation and maintenance of the existing irrigation schemes. Construction of small-scale community based irrigation schemes and water wells for households will be emphasized. These can limit the effect of droughts, can be used for domestic consumption and horticulture production, and solve the problem of seedbed preparation. Effects will also be made to mobilize loans and grants to invest in medium and large-scale irrigation schemes in high potential area. Reaching the targets is thus a joint effort between the State and the communities.

Also in Lao PDR there are many obvious factors and constraints for sustainable development in irrigation management such as constraint on irrigation works, constraint on the government policy, constraint on stakeholder participation in irrigation management etc.

Constraint on irrigation works

1. Physical constraints

Laos is an essentially mountainous country with 80% of its areas situated above 200 m, while the remaining is made up of plains along the Mekong River and its tributaries. Heights are improper to agriculture with its excessive humidity causing a general deficit in rice; this is different from plains along the Mekong River and its tributaries where irrigation can be conveniently be built up and soil is most favorable to cultivation.

2. Climatic constraints

Two seasons alternate with variation of temperature between 18 and 21 degree Celsius in the dry season and 25 to 28 degrees Celsius during the rainy season between June and October. This is accompanied by a change in the humidity from 30 percent to 98 percent and rainfall from 1300 mm in the northern area to 3,700 mm in the southern plain. The maximum rainfall would intervene from July to August.

However, in some years with uneven rainfall, the need for irrigation to supplement insufficient rainfall varies from 5,000 m^3 to 7,000 m^3 per hectare depending on areas. When drought strikes, irrigation becomes the only means to sustain the rice cultivation as well as the cultivation of other crops that would require water from the river around 17,000 m3 to 20,000 m^3 per hectare.

Plains are watered by the Mekong River as well as other rivers such as Nam Ngum, Nam Ngiep, Nam San, Se Bang Fay, Se Bang Hieng, Se Don, Se Kong. It is not unusual that drought strikes these areas at the beginning and at the end of the cultivation season. While during the rainy season, the river water level is rising rapidly (MRCS Country report, 2007), especially between July and September causing severe floods such as in 1966, 1968, 1970, 1971, 1974, 1978, 1990, 1991, 1995, 1996, 1998, 2000, and 2002 with loss of live and materials as showed the following available figures:

Table 1 Statistic of Flood damages in Lao PDR

Year	Damages (in US$ millions)	Areas damaged
1966	13.80	Central Laos
1976	9.00	North Laos
1978	5.70	Central and South Laos
1993	21.00	Central and South Laos
1994	21.15	Central and South Laos
1995	35.50	Vientiane Plain, Central and South Laos
1996	21	Central and South Laos
1998	3.50	Central and South Laos
2000	5	Central and South Laos
2002	3.50	North, Central, South Laos
2008	15	Vientiane Plain, Central and South Laos

3. Single cropping per year, and dependency on rainfall.

The Lao People's Democratic Republic has invested in building-up irrigation schemes aiming at meeting needs in water for agriculture as well as household use. However, the efficiency of irrigation projects carried out is still low. The designing, the preparation, the maintenance and management are not up to standard causing the agriculture to still be of one harvest and essentially dependant of erratic rainfall.

Governmental policy (Country Report, 2007)

1. Irrigation within the government policy to lift the country of the less developed in 2020

In order to achieve this goal, the government has adopted five working plans regarding food production as the government set the year 2000 to bring the country into food self-sufficiency. Such an ambitious target can be attained only through the consolidation, expansion, maintenance, and efficient use of irrigation. Such a target will be more difficult to be attained in the remote provinces of Laos' upland. The four other working plans are about commodity production, limitation and eradication of shifting cultivation and environment protection, comprehensive rural development and human resource development.

In the main, the development of water resources, particularly irrigation has the following roles:

i) To expand the development of irrigation to the rural areas;

ii) To change natural economy, semi-natural into commodity production;

iii) To protect the environment by stabilizing the areas of production and to create new settlements for people practicing previously slash and burn cultivation, as well as to avert all setbacks linked to the irrigation works;

iv) To build new irrigation projects, to rehabilitate and to improve existing irrigation projects, to strengthen facilities for the implementation of the development of irrigation; and

v) To develop human resources, especially at managerial level.

In term of irrigation development plan is placed on the fourth priority of the six-government agriculture strategies. The major key objectives of irrigation project development is to increase rural income and to stabilize rice availability by expanding irrigated areas for both wet season and dry season and to improve performance of the operation and maintenance of existing irrigation systems.

Currently, the government has been trying to adopt Irrigation Management Transfer (IMT) policy nationwide for all the irrigation schemes to transfer to ownership as well as associated cost to beneficiary farmers to reduce subsidies of irrigation sector from the government. However, the processes have not been made smoothly and yet successful because there are a lot of challenges, and issues still remaining. These issues include poor and deterioration of existing irrigation, lacking of farmers' incentive due to low income from rice cultivation caused by uncertainty and unavailability of market particularly in the rural area, and cropping intensity in the dry season under irrigation is still low. In order words, farmers are not willing to grow rice in dry season and these affects to the serious issue in cost recovery. The government, therefore, currently is working on rehabilitation of existing facilities appareling with strengthening of Water User Association (WUA) to recover and upgrade their function before IMT is materialized.

Through IMT process, agricultural sector makes provision for the development of responsibilities and activities to Provincial Agriculture and Forestry Offices (PAFOs) and District Agriculture and Forestry Extension Offices (DAFEOs). This process of devolution of responsibility is in line with Prime Ministerial Degree 01/'PM of Lao PDR on decentralization and this is central to the strategy, and an innovative approach to agricultural extension has been adopted. This approach relies heavily on subject matter specialist at provincial level and generalist extension staff at district level.

Thus, in terms of communities forming WUA who are then able to manage irrigation efficiently and accept responsibility for repairs, upkeep, maintenance, and also capital replacement under IMT agreements, irrigation policy and implementation has not been successful. Communities are not able to manage assets sustainably. Irrigation schemes are not well maintained and water user organization is very weak. Operations costs such as electricity are not paid in full by the majority of users resulting in large debts nationally to Electricite du Laos (EdL). Scheme infrastructure depreciates rapidly with the lack of maintenance and repair resulting in investment intensive rehabilitation cycles of usually less than 10 years. Village Development Funds (VDF) have in general failed to contribute to irrigation maintenance and development and IMT has not improved system sustainability.

The factors for success for IMT are:

i) In terms of cropping potential and also in terms of community demand for irrigation development and commitment to maintain and use the facilities. The irrigation scheme must be suitable for crop diversification and have market logistic potential – must assess soils, water resources, cropping patterns;

ii) Identify all stakeholders and then build mechanisms to ensure they participate and are included as members. The service boundaries of the scheme must be properly identified and the service within those boundaries must be of an acceptable standard in terms of water supply and delivery. This effectively means that one waits until a design and canal layout has been produced. Members of WUAs will include seasonal land renters who do not normally reside in the project villages. These stakeholders need to be regarded as seasonal members and subjected to WUA regulations. Absentee land owners must be finally responsible for any debts/problems by renters of their land;

iii) Provide clear and exhaustive explanation and details of the terms of IMT – what are benefits and costs. Clearly define government support for the emerging WUAs – a tangible and transparent statement of conditions and support so that each party to the IMT agreement can be confident that the other's role and responsibilities will be fulfilled when needed. This is particularly the case in regards to large scale repairs. Financial and cost sharing arrangements must be specified clearly;

iv) Communities must see and realize a benefit from IMT and there must be a net tangible gain to the transferee – this can be in terms of improved service or better, more timely repairs. IMT must be a demand driven response from government, not a top-down drive initiative to save money;

v) Irrigation scheme design should be complex enough for efficient water distribution management in order to support crop diversification and land use zoning, and sound water management and conservation by users.

vi) IMT is more appropriate in communities seeking to expand their market production. These communities have more capacity than those dealing with food security issues and have savings to invest in irrigated agriculture development and are already accustomed and involved in market dynamics;

vii) Communities need to have a good idea of how they are going to exploit the improved resource particularly in regards to crop diversification and market opportunities. Market linkages to WUA based production groups are necessary drivers for successful IMT. These are not usually the poverty stricken communities;

vii) The economics must support IMT in order to accommodate the increased financial burden of maintenance and replacement to users. It would indicate that IMT is best suited then to schemes that have a significant level of dry season cropping. In developing rural communities the basic rationale is: Wet season grow rice for household consumption, dry season grow cash crops for market. There are many cases where irrigation schemes have been built or rehabilitated solely in order secure the wet season rice crop and with virtually no opportunity for dry season cropping. This then secures rice for the community – but they still have no extra cash generated with which to cover the increased O&M costs; and

ix) And of course, in any irrigation development it is vital that irrigation users and WUAs receive sufficient training in system use and planning, operations and maintenance, small scale repair, pump operation and service.

WUA management committees must be trained in Water User Organization (WUO) management functions such as accounting, member administration and in conducting member meetings. Water users must receive the support of agriculture extension agencies for both food and cash crops in order to make the most of the water resource in economic terms. Where appropriate market development training should also be included in farmer training programs.

2. Progress in irrigation areas

Consequently, the last few years, especially since the 1996 flood, the government has given a great importance to the irrigation issue translated by the leap forward of the irrigated area during the dry season from 24,000 ha in 1996 to 214,626 in 2002. By 2002, this policy is translated by investing in pumping stations and individual pumps (amounting to 3,828), building dams, weirs (totaling 786), constructing reservoirs (numbering 184) to retain water, 69 water gates of canals and dykes, 17,604 traditional weirs, 116 gabions with the result that the irrigated areas in 2007 reach 310,170 ha in the rainy season, and 214,823 ha in the dry season as shown the following available figures:

Table 2 Irrigated Area by various techniques in 2002, 2003 and 2007

Type of System	No. of Systems			Wet Season Irrigated Area (ha)			Dry Season Irrigated Area (ha)		
Year	2002	2003	2007	2002	2003	2007	2002	2003	2007
Small dam (concrete weir)	786	867	867	56,822	53449	53,449	25,873	25,809	25,809
Storage reservoir	184	222	222	22,896	24,474	24,474	11,131	10,681	10,681
Pumping	3,828	4568	4,586	166459	16,8891	168,195	144,630	145,942	145,897
Watergates and dikes	69	69	69	9,749	9,864	9,864	2,614	2,469	2,469
Traditional weir	17,604	18794	15,346	47954	49676	50,371	29,261	28,452	28,488
Gabion weir	116	157	157	3,168	3,817	3,817	1,117	1,479	1,479
Total	22,587	24,677	21,247	307,048	310,171	310,170	214,626	214,832	214,823

Comparing to the past, the irrigated area has significantly increased as shown the following table 3:

Table 3 Statistic Irrigated Area from 1991 to 2007

No	Year	Rainy Season(ha)	Dry Season(ha)
1	1991	136,000	16,000
2	1992	138,000	18,000
3	1993	140,000	20,000
4	1994	145,000	22,000
5	1995	150,000	26,000
6	1996	156,000	28,000
7	1997	164,000	45,000
8	1998	216,890	75,000
9	1999	258,200	124,234
10	2000	295,535	197,131
11	2001	300,054	214,131
12	2002	307,097	214,625
13	2003	310,171	214,832
14	2007	310,170	214,823

It results that about 65% of agricultural production of the country, as well as 20% of rural population benefit from irrigation.

3. Features of irrigation schemes

Most of the irrigation schemes located in the upland and mountainous areas are of small size (less than 100 ha), and are not made in concrete, but with natural materials. They are temporary, last only one year, and subjected to embankment erosion.

Of the 800,000 ha cultivated, only a small portion is benefiting of irrigation and mostly located along the Mekong River and its tributaries (Vientiane capital, provinces of Vientiane, Bolikhamsay, Khammouan, Savannakhet, Saravane, Champassak, Sekong, Attapeu) with water provided by individual pumps or pumping stations using electricity or petrol. Medium (101 to 1,000 ha) or huge (more than 1,000 ha) scale irrigation schemes can be found in these provinces. The pumping stations needs to be maintained, improved, and even canals and ditches need to be under constant maintenance. Potentialities remain vast, but to exploit them fully, old problems have to be solved first such as the pumping stations or individual pumps.

In mountainous areas (Northern provinces: Phongsali, Bokeo, Luang Namtha, Oudomxay, Huaphan, Sayaboury, Luang Prabang, and Xieng Khuang), characterized by small scale irrigation schemes (irrigated area of less than 100 ha) approximately 18,150 temporary traditional irrigation works have been carried out by the population using woods, logs, or rocks, thus the name of “primitive weirs” or “people’s community’s weirs”.

Strategic vision of the government for 2005~2010

1. Irrigation policy for 2005~2010

As the Government sets the target to produce 2.5 million tons in 2005, 3.5 millions tones of rice in 2010 and 5.2 millions in 2020, priority in expanding irrigation and surface irrigated is significant. Furthermore, irrigation is needed to help decreasing the slash and burn cultivation which has to be ended by 2010, to cease opium cultivation, and to make central and southern Laos as base for commodity production. This two-fold policy regarding irrigation in the main would provide the following projection:

Table 4 Cultivated areas (2005-2020)

Farming systems	Year 2005 (ha)	Year 2010 (ha)	Year 2020 (ha)
Area cultivated in the rainy season	350,000	540,000	800,000
Area cultivated in the dry season	250,000	300,000	400,000
Irrigated rice-field	130,000	180,000	250,000

In the meantime, the Government has to promote and to support small-scale irrigation project initiated or practiced by families or communities, to foster the participation of farmers and private sector in the irrigation development, and to secure the socio-economic development as well as the protection of the environment.

The figure 3 showed that the cultivated areas in rainy season increase sharply from 2010 to 2020. That indicates the government policy is focused to extend cultivated areas for food security in term of sustainable irrigation development.

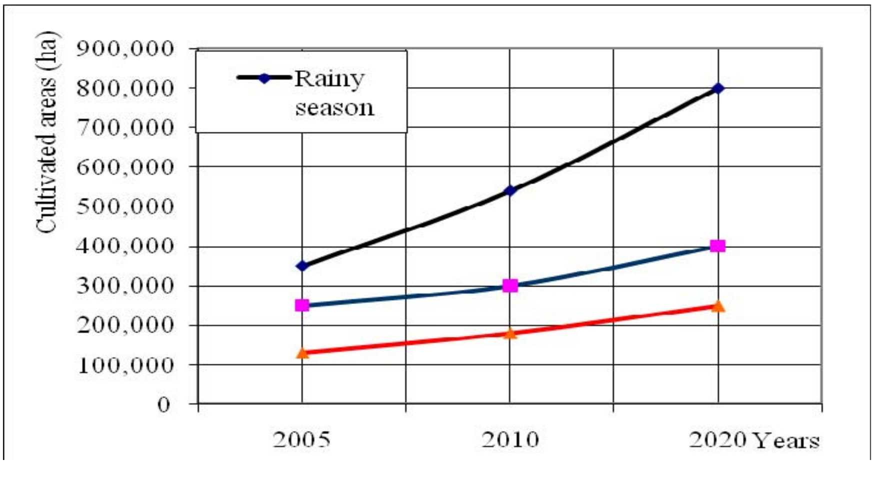


Figure 3 Strategic vision for sustainable irrigation development by increasing cultivated area (2010~2020)

2. Strategy in the development and the practice/ organization of irrigation

This strategy needs:

i) To focus on the development of irrigation in northern Laos where slash and burn as well as opium cultivation are practiced, and in central and southern Laos to promote commodity production;

ii) To survey and to gather data on potentialities of water resources;

iii) To edict laws, regulations and rules for expansion and implementation of irrigation such as: technical standards, regulations to be carried out strictly;

iv) To train officials dealing with irrigation within the provinces and districts;

v) To conduct feasibility study of prioritized projects, to design in detail and to implement;

vi) To promote investment in irrigation by private sector, community, and foreign financial organization through direct assistance and short and medium term loan.

vii) To mobilize rural population to participate in the development of irrigation;

viii)To build rural road connecting irrigation network to the markets, and to create facilities for the promotion of commodity production; and

ix) To salvage and modernize the whole of traditional irrigation works to insure high efficiency and to expand the irrigated surface.

3. Working plan to reach the assigned goals embedded in the projection figures

A working plan was elaborated:

i) To survey and estimate natural resources such as soil, water, seeds, as well as the living conditions of the population.

ii) To survey and to evaluate the situation, needs and the strength of the socio-economic development.

iii) To survey and to forecast natural cataclysms such as drought, flood, as well as the potentiality to meet requirement in water for various uses;

iv) To determine the use and needs of water by factories, and to strike the balance in the projected figures of the development plan up to 2010;

v) To analyze options in the development of water resources to support the socio-economic development: to meet requirement in water for drinking and individual use, agricultural and industrial production, and to concentrate on averting and eradicating damages resulting from floods;

vi) To determine methods or steps of investment capable in the implementation of economic development suitable with the technical capabilities and economic potentialities in the areas; and

vii) To rely on existing methods to supply irrigation water such as reservoirs, dams, pumping stations and individual pumps, and water gates of canals in plains. While traditional weirs and gabions will be used in mountainous areas.

4. Maintenance and sustainability of irrigation system

Past experience reveals the importance of these issues such as:

i) To organize associations of users of irrigation water, with adopted statute and rules to operate the association;

ii) To train administrative officers of the associations of users of irrigation water for them to be knowledgeable about Water Law and Environment Protection Law, the management as well as the calculation of the servicing of water, the business management, as well as the loan which was granted;

iii) To train groups of irrigation system users to be aware of management work and the use of water such as plan to cultivate according to season, the opening and closure of water, plan to maintain the system and the implementation;

iv) To train members of associations of users of irrigation water to be knowledgeable about allocating water, the maintenance and strengthening of the system, and the implementation;

v) To hand-over projects to the associations of users of irrigation water;

vi) Irrigation officials as well as officials assisting the authorities of the provinces, and districts must follow-up and provide advice about the management of the irrigation system to the associations of users of irrigation water as well as its members; and

vii) To promote and to encourage intensive agriculture by spreading technology among the farmers.

2.3 Theory of farmers' participation in water resource management

The ideology and rhetoric of participation have long infused development theory and practice (Norman, Uphoff. 2008). The underpinning of the concept is that participation is conducive to greater efficiency and equity in management; that problems are better solved by those who experience them, and that projects are better maintained and more sustainable when designed and taken care of by the direct beneficiaries. Participation can be conceived as a tool (for better management) or as a process (with view to empowerment). In the water sector, there have been repeated and widespread attempts to replicate the traditional organizations for water management, observed in small communal systems (based on small tanks, run-of-the-river diversions, springs and traditional weir), adapting those to large-scale schemes. Experiences with participatory irrigation management or management transfer (turnover) have had mixed results, mostly because of a lack of genuine farmer empowerment and redistribution of roles, and of limitation in hydraulic infrastructures.

The focus of water resources management has also shifted accordingly, from technology transfer towards decentralized and user-centred approaches emphasizing participation and local organizational development as explained by (Clyma, 1989), (Uphoff, 1986, and Korten, 1984). This has changed the development problematic in two ways: Firstly, the focus has shifted to the promotion of local water management through user organizations; secondly, design approaches have also shifted towards participatory design processes to support organizational evolution. More recently, attention has been shifted towards promotion of local governance and transfer of irrigation management to user groups commonly referred to as Water Users Associations (WUAs), has been central in the irrigation reform process (Vermillion, 1999; Meinzen-Dick *et al*., 2002, Johnson *et al.*, 2002). This shift has been in response to structural adjustment and neo-liberal policies of the 1990s and participation of relevant stakeholders is considered as prerequisite to create effective forms of local organization to govern and manage irrigation water.

The general aspect of stakeholders' participation in water management as describing below:

1. Real Participation

Water is a subject in which everyone is a stake-holder. Real participation only takes place when stakeholders are part of the decision-making process. This can occur directly when local communities come together to make water supply, management and use choices. Participation also occurs if democratically elected or otherwise accountable agencies or spokespersons can represent stakeholder groups. Additionally, there are circumstances in which participation in decision-making can take place through market processes; if appropriate pricing systems are in place, local governments, community organizations or irrigation districts could signal their demands for bulk water services. The type of participation will depend upon the spatial scale relevant to particular water management and investment decisions and upon the nature of political economy in which such decisions take place (Norman, Uphoff, 2008).

2. Participation in more than consultation

Participation requires that stakeholders at all levels of the social structure have an impact on decisions at different levels of water management. Consultative mechanisms, ranging from questionnaires to stakeholder meetings, will not allow real participation if they are merely employed to legitimize decisions already made, to defuse political opposition or to delay the implementation of measures which could adversely impinge upon a powerful interest group.

3. Achieving consensus

A participatory approach is the only means for achieving long-lasting consensus and common agreement. However, for this to occur, stakeholders and officials from water management agencies have to recognize that the sustainability of the resource is a common problem and that all parties are going to have to sacrifice some desires for the common good. Participation is about taking responsibility, recognizing the effect of sectoral actions on other water users and aquatic ecosystems and accepting the need for change to improve the efficiency of water use and allow the sustainable development of the resource. Participation will not always achieve consensus, arbitration processes or other conflict resolution mechanisms will also need to be put in place.

4. Creating participatory mechanisms and capacity

Governments at national, regional and local levels have the responsibility for making participation possible. This involves the creation of mechanisms for stakeholder consultation at all spatial scales; such as national, basin or aquifer, catchment and community levels. However, while the creation of consultative mechanisms is necessary, it will by itself not lead to real participation. Governments also have to help create participatory capacity, particularly amongst women and other marginalized social groups. This may not only involve awareness raising, confidence building and education, but also the provision of the economic resources needed to facilitate participation and the establishment of good and transparent sources of information. It has to be recognized that simply creating participatory opportunities will do nothing for currently disadvantaged groups unless their capacity to participate is enhanced.

5. The lowest appropriate level

Participation is an instrument that can be used to pursue an appropriate balance between a top-down and a bottom-up approach to integrated water resource management. For some decisions the appropriate decision unit is the household or the farm; participation depends on the provision of mechanisms and information to allow individuals and communities to make water sensitive choices. At the other end of the spatial scale the management of international river basins will require some form of cross-national coordinating committees and mechanisms for conflict resolution.

6. Involvement of women in decision-making

Women's participation as decision-makers is interwoven with gender hierarchies and roles within different cultures leading to the existence of communities that ignore or impede women's participation in water management. Although "gender issues" have been reflected in all statements on IWRM since the Dublin and Rio conferences, there is still a long way to go before rhetoric is replaced by operational mechanisms and actions to ensure an equitable participation of women in IWRM. Therefore special efforts must be made ensure women's participation at all organizational levels.

7. Women as water users (Davran, K. M., 2005)

It is widely acknowledged that women play a key role in the collection and safeguarding of water for domestic and in many cases-agricultural uses, but that they have a much less influential role than men in management, problem analysis and in the decision-making process related to water resources. The fact that social and cultural circumstances vary between societies suggests that the need exists to explore different mechanisms for increasing women's access to decision-making and widening the spectrum of activities through which women can participate in water resource management.

8. Integrated water resource management requires gender awareness

In developing the full and effective participation of women at all levels of decision-making, consideration has to be given to the way different societies assign particular social, economic and cultural roles to men and women. There is a need to ensure that the water sector as a whole is gender aware, a process which should begin by the implementation of training programmes for water professionals and community or grass root mobilizes.

9. Integration of all stakeholders in the planning and decision process

The involvement of the concerned stakeholders in the management and planning of water resources is universally recognized as a key element in obtaining a balanced and sustainable utilization of water. But in many cases stakeholders represent conflicting interests and their objectives concerning water resources management may substantially differ. To deal with such situations the IWRM should develop operational tools for conflict management and resolution as well as for the evaluation of trade-offs between different objectives, plans and actions. An important issue here is the need to identify and designate water resources management functions according to their lowest appropriate level of implementation; at each implementation level the relevant stakeholders need to be identified and mobilized.

10. The different development context of Participation

Participation can be defined in many ways and is often seen as transaction between the 2 farmers and the engineers (or facilitators). Participation does not operate in vacuum; it is linked with certain development objectives. It is argued here that there are different development contexts linked to participatory frameworks for intervention, and there are different domains of action in participation (Khanal, 2003; Vincent and Khanal, 2002; Vincent, 1997). The different development contexts of participation do have different concepts of innovation and different sets of participatory methodologies linked with them.

a) Development context 1: Economic development and modernization

In this context, participation is an approach (by agencies) to induce increases in performance or impact, through providing conditions or incentives that enable farmers to take on new responsibilities and opportunities. Participation here has moved beyond project execution to policy reform and self-governance, and even been considered the way to operationalize decentralization as the motor for democratic transformation (Cornwall, 2001). Innovation then concerns new activities that improve linkages between resource use and production – new techniques, artifacts or institutional relations. In irrigation water management, its primary focus is on institutional reform to both local organization and the irrigation bureaucracy, but also heavily focused to system modernization to provide better working conditions for farmers. It lays emphasis on participatory design processes to support evolving organization, and calls for accountability between the irrigation agency and the WUA and between the WUA and the farmers. Thus, participatory approaches that allows local negotiation and evolutionary change rather than blue-print models work best. However, it is vulnerable to blueprint ideas about WUA development and new technologies, and over-expectation of what users can do. Bureaucratic reform is a time-consuming process, and is often outside the framework of funding agencies. This context of participation is the backdrop to the ongoing Irrigation Management Transfer programs (IMT) and its policy tools and intervention approaches.

b) Development context 2: Joint planning and problem solving

Here, participation is a process through which stakeholders influence, share control and work together to achieve desired change. Innovation is shown through the changed behavior of the people involved, and the sharing of knowledge and skills. This context focuses on the generation, transfer and exchange of knowledge as a means to beneficial change. It recognizes that technology is not neutral and technological change should reflect local needs and knowledge. Also that people have a right to self-determination over their development. In the field of technology development in this context, Participatory Technology Development (PTD) has got considerable attention as an approach.

However, the technical biases of many engineers, and their sense of status that makes them unwilling to accept farmers as partners and lengthy bureaucratic process often yields failure to make design process participatory.

c) Development context 3: Social inclusion, improved equity and reduced vulnerability.

Participation here is organized efforts to increase control over resources and regulative institutions in given situations on the part of groups and movements of those hitherto excluded (a definition from an ILO program). Innovation is the delivery of different benefits to different people. This context recognizes the tensions and complex politics of negotiating change in many different arenas, but needs highly motivated and conscientized actors to empower change. It is committed to capacity development of the users groups and concentration on the certain marginalized groups. However, the danger may come from its conscientization and political action which may lead to collapse of existing management arrangements without new forms to replace it.

Water management in recent years is more focused to the development context 1 and the other two are seen as supporting elements to achieve better service provisions.

d) Domains of participation

There are also different domains of actions in participation between users, and other social actors. These different stakeholders can have different interests and sphere of influences in local water management. The different development contexts of participation together with the different domains of interactions constitute a 'Participation Complex' which shapes the outcomes of local water management. In a real-world situation, a program execution can involve all the different development contexts together; requiring understanding of the clashes these can bring between people with different aims and objectives in participation.

11. Current approaches to local Water Management

The current approaches to local water management can be summarized into two key actions:

- Development and empowerment of Water User's Associations (WUAs) as new form of governance to govern and manage irrigation water.
- Supporting the new organization through participatory design process to help build up their capacity to manage water and provide better working conditions through more compatible technologies and water management practices.

a) WUAs as new form of governance

Work on WUA design and development has generally followed two approaches to institutional design. Researchers like (Ostrom, 1992) emphasize governance as a dimension of management involving the generation of rules for management practice. Another group is more focused in identifying conditions under which the WUA can perform irrigation management tasks (see for example, (Vermillion, 1995), (Vermillion and Sagardoy, 1999), (Groenfeldt, 1999); (Meinzen-Dick *et al.*, 2002). They are more focused on organizational type, size of organization, compatibility of structures and clear water rights. Both of these approaches are more concerned over finding appropriate conditions and generating rules to govern and manage irrigation water. However, they fail to understand governance as possible under divergence forms of regulation and control.

b) Participatory support processes and local water management

Participatory and process-based intervention emphasizing participation of stakeholders and social learning has been widely called for to support water management. However studies have shown that they fall short in real practice. Though efforts have been made to shift away from blueprint towards the process approaches, in reality, blue-print ideas about project planning and implementation dominates the intervention, and learning and participation are mostly confined at local level of project implementation. Hierarchical organizational structure, lack of organizational learning, shorter time frames, failure to link the project with the broader development objective all pose barriers in maintaining participatory processes. Participatory and process-driven approaches have become a sort of 'good theory, poor practice'. There is a need for fundamental changes in the way projects are designed and implemented to achieve participatory development in real world situation.

Another major constraint in embedding participatory approaches in water management comes from lack of initial learning of the system environment both by the users and outside facilitators. Water resources systems including irrigation systems are socio-technical systems and technology of the system shapes and are shaped by ecology and society. Designing for participation for water management should thus begin considering both the human and the physical dimension of irrigation systems. The strength of participatory design depends first on what people, both users and designers know about the system, and its opportunities and constraints. Use of participatory approaches without understanding of system environment ultimately leads to its instrumental use without any scope for beneficial change.

In Lao PDR , new policies are said to include "fully decentralized 'bottom-up' participatory planning with the governmental system" (Khamhung, 2001) but there is little sign that this translates to giving people more say on, for example, the large infrastructures that are planned in the country (e.g., Nam Theun 2 or the Theun-Hinboun project. The fact that NGOs are not allowed in Laos also gives a measure of the limits within which civil society is allowed to participate. According to (Khamhung. 2001), the rationale for the policy to transfer ownership and associated costs of irrigation to farmer users is based on the belief that "traditional irrigation systems have been efficiently managed by farmers' communities" and also on the economic necessity for the government to reduce agriculture-sector subsidies. The 1998 Prime Minister's Order No. 26/PM on transferring irrigation projects to community organizations aims at "promoting and supporting the role and responsibility of WUAs in the management of irrigation systems; assisting in the reduction of the responsibilities of government agencies in the routine management of irrigation systems; ensuring the smooth transition of the full transfer of ownership of all irrigation infrastructure to WUAs; and improving the efficiency of operations, management and water distribution on all irrigation systems" (Khamhung, 2001).

2.4 Optimization techniques

One of the most fundamental principles in our world is the search for an optimal state. As long as humankind exists, we strive for perfection in many areas. We want to reach a maximize degree of happiness with the least amount of effort. In the economy, profit and sale must be maximized and costs should be as low as possible. Therefore, optimization is one of the oldest of sciences which even extends in to daily life (Tomas Weise, 2008).

If some things is importance, general, an abstract enough, there is always a mathematical discipline dealing with it. Global optimization is the branch of applied mathematics and numerical analysis that focus on, well, optimization. The goal of global optimization is to find the best possible elements x* from a set X according to a set of criteria $F = \{f_1, f_2, ..., f_n\}$. These criteria are expressed as mathematical functions, the so-called *objective functions*. The objective function $f : X \mapsto Y$ with $Y \subseteq R$ is a mathematical function which is subject to optimization.

The global optimization is about finding the best possible solutions for given problems. In the case of optimizing a single criterion f, an optimization is either its maximum or minimum, depending on what we are looking for. Figure 4 illustrates such a function f defined over a two-dimensional space X = (X_1, X_2). As outlined in this graphic, we distinguish between local and global optima. A global optimum is an optimum of the whole domain X while a local optimum is an optimum of only a subset of X.

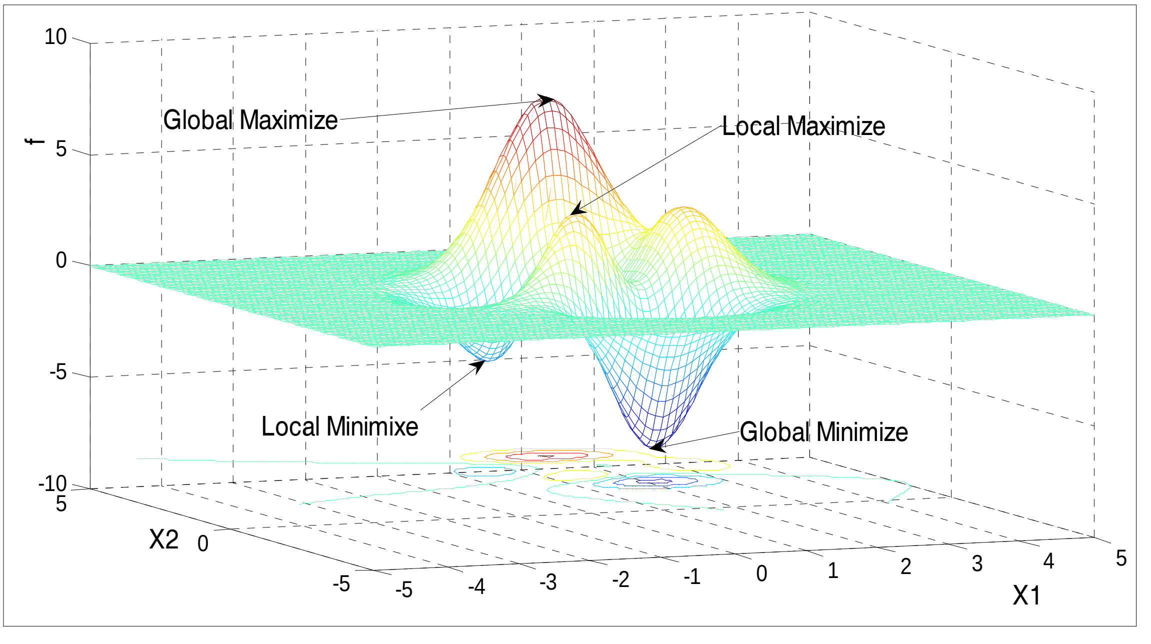


Figure 4 Global and local optima of two-dimensional function.

A local maximum $\hat{x}_l \in$ X of one objective function f : X $\mapsto$ R is an input element with $f(\hat{x}_l) \geq f(x)$ for all x neighboring $\hat{x}_l$.
If X $\in R^n$ we can write:

$$\forall \hat{x}_l \exists \varepsilon > 0 : f(\hat{x}_l) \geq f(x) \forall x \in X, \ |x - \hat{x}_l < \varepsilon| \tag{2.1}$$

A local minimum $\hat{x}_l \in$ X of one objective function f : X $\mapsto$ R is an input element with $f(\hat{x}_l) \leq f(x)$ for all x neighboring $\hat{x}_l$.
If X $\in R^n$ we can write:

$$\forall \hat{x}_l \exists \varepsilon > 0 : f(\hat{x}_l) \leq f(x) \forall x \in X, \ |x - \hat{x}_l < \varepsilon| \tag{2.2}$$

A local optimum $x_l^* \in$ X of one objective function f : X $\mapsto$ R is either a local maximum or a local minimum.

A global maximum $\hat{x} \in x$ of one objective function f : X $\mapsto$ R is an input element with $f(\hat{x}) \leq f(x) \forall x \in$ X.

A global minimum $\breve{x} \in$ X of one objective function f : X $\mapsto$ R is an input element with $f(\breve{x}) \leq f(x) \forall x \in$ X.

A global optimum $x_l^* \in$ X of one objective function f : X $\mapsto$ R is either a global maximum or a global minimum.

Even a one-dimensional function f : X = R $\mapsto$ R may have more than one global maximum, multiple global minima, or even both in its domain X. Take the cosine function for example: It has global maxima $\hat{x}_1$ at $\hat{x}_l = 2i\pi$ and global minima $\hat{x}_1$ at $\hat{x}_l = (2i+1)\pi$ for all $i \in$ Z. The correct solution of such an optimization problem would then be a set X^* of all optimal inputs in X rather than a single maximum or minimum. Furthermore, the exact meaning of *optimal* is problem dependent. In single-objective optimization, it either means minimum or maximum. In multi-objective optimization, there exist a variety of approaches to define optima.

Global optimization techniques are not just used for finding the maxima or minima of single functions f . In many real-world design or decision making problems, they are rather applied to sets F consisting of $n = |F|$ objective function f_i, each representing one criterion to be optimized.

$$F = \{ f_i : X \mapsto Y_i : 0 < i \leq n, Y_i \subseteq R \} \tag{2.3}$$

The example below in figure 5 is showed the multi-objective function for finding the maximal problem with two independent objective functions $F_1 = \{ f_1, f_2 \}$. Both objective functions have a real number R as problem space

X_1 . The maximum of f_1 is $\hat{x}_1$ and the largest value of f_2 is $\hat{x}_2$ (Tomas Weise, 2008). In figure we can easily see that f_1 and f_2 are partly conflicting. Their maxima are at different locations and their even exist areas where f_1 rises while f_2 falls and vice versa.

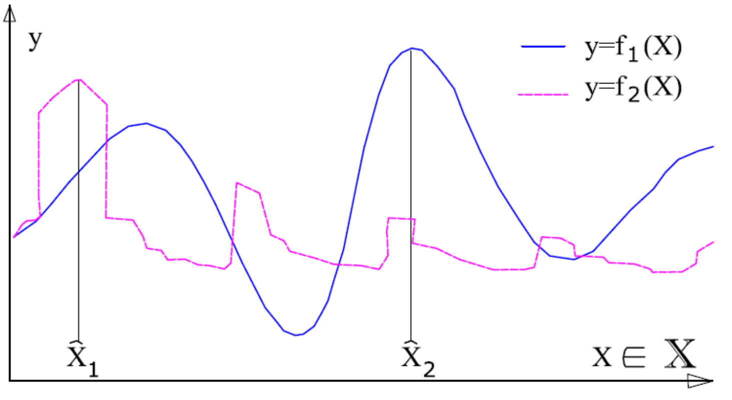


Figure 5 Two function f_1 and f_2 with different maxima $\hat{x}_1$ and $\hat{x}_2$.

Figure 2-6 is showed the objective function f_3 and f_4 are mappings of a two dimensional problem space $X_2 \subset R^2$ to the real number R that are to be minimized. Both functions have two global minima; the lowest value of f_3 are $\breve{x}_1$ and $\breve{x}_2$ whereas f_4 get minimal at $\breve{x}_3$ and $\breve{x}_4$. It should be note that $\breve{x}_1 \neq \breve{x}_2 \neq \breve{x}_3 \neq \breve{x}_4$.

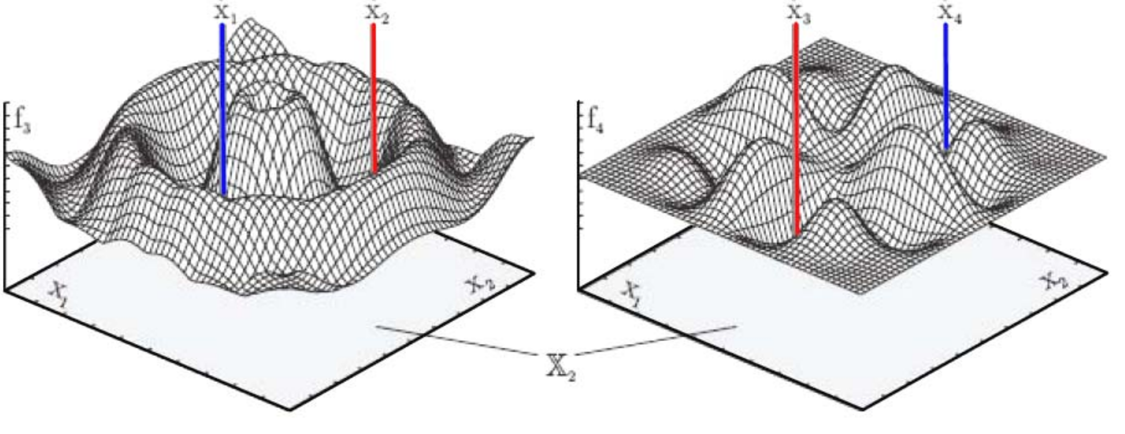


Figure 6 Two functions f_3 and f_4 with different minima $\breve{x}_1, \breve{x}_2, \breve{x}_3$ and $\breve{x}_4$

2.5 Linear Programming model

A linear programming may be defined as the problem of maximizing or minimizing a linear function subject to linear constraints. The constraints may be equalities or nonequalities. Not all linear programming are so easily solved. There may be many variables and many constraints. Some variables may be constrained to be negative and others unconstrained. Some of variables may be equalities and others inequalities. However, two classes of problems, called here the *Standard maximum problem* and *Standard minimum problem,* play a special role. In these problems, all variables are constrained to be negative, and all main constraints are inequalities.

If given an *m*-vector, $b=(b_1,....,.b_m)^T$, an *n*-vector, $c=(c_1,.....,c_n)^T$, and an *mxn* matrix, of real numbers

$$A=\begin{pmatrix} a_{11} & a_{12} & \ldots\ldots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix}$$

a) The Standard Maximum Problem

Find an *n*-vector, $x=(x_1,.....,x_n)^T$, to maximize

$$c^T x = c_1 x_1 + \ldots + c_n x_n$$

This function is called the *objective function.* It often seems that real-world problems are most naturally formulated as minimizations, but when discussing mathematics it is usually nicer to work with maximization problems. In addition to the objective function, the above function also has constraints. Some of these constraints are really simple, such as the requirement that some decision variable nonnegative. Others are more involved. But in all cases the constraints consisted of either equality or an inequality associated with some linear combination of the decision variables.

Subject to the constraints

$$\begin{matrix} a_{11}x_1 & a_{12}x_2 & \ldots\ldots & a_{1n}x_n \le b_1 \\ a_{21}x_1 & a_{22}x_2 & \cdots & a_{2n}x_n \le b_2 \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1}x_1 & a_{m2}x_2 & \cdots & a_{mn}x_n \le b_m \end{matrix} \quad (\text{or } \; Ax \le b)$$

and

$$x_1 \ge 0, x_2 \ge 0,...., x_n \ge 0$$

b) The Standard Minimum Problem

Find an *m*-vector, $y=(y_1,....,y_m)$, to minimize

$$y^T b = y_1 b_1 + ... + y_m b_m$$

subject to the constraints

$$\begin{matrix} a_{11}y_1 & a_{12}y_2 & ..... & a_{1n}y_n \geq c_1 \\ a_{21}y_1 & a_{22}y_2 & \cdots & a_{2n}y_n \geq c_2 \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1}y_1 & a_{m2}y_2 & \dots & a_{mn}y_n \geq c_m \end{matrix} \quad (\text{or } \; y^T A \leq c^T)$$

and

$$y_1 \geq 0, y_2 \geq 0,...., y_n \geq 0$$

Note that the main constraints are written as $\leq$ for the standard maximum problem and $\geq$ for the standard minimum problem.

The linear programming is commercially available program. The program is suitable for finding problems of optimization of water resources allocation, diet for different kind of foods, transportation, managing a productivity facility, network flow etc., by using the method of Simplex or Interior-point method for searching the optimal value which appropriately of the problems.

The Simplex method

Consider the general linear programming problem presented in standard form:

maximize

$$\max z = \sum_{j=1}^{n} c_j x_j$$

subject to $\sum_{j=1}^{n} a_{ij} x_j \leq b_i \quad i = 1,2,....,m$

$$x_j \geq 0 \qquad j = 1,2,....,n$$

slack variables are equal to

$$s_i = b_i - \sum_{j=1}^{n} a_{ij} x_j \tag{2.4}$$

As the simplex method proceeds, the slack variables become intertwined with the original variables, and the whole collection is treated the same. Therefore, it is at time convenient to have a notation in which the slack variables are more or less indistinguishable from the original variables.

$$(x_1,......., x_n, s_1,..........s_m) = (x_1,.........., x_n, x_{n+1},........, x_{n+m})$$

That is let's $x_{n+1} = s_i$. With this notation, we can rewrite (2-3) as

$$x_{n+1} = b_i - \sum_{j=1}^{n} a_{ij} x_j$$

This is the starting dictionary. As the simplex method progress, it moves from one dictionary to another in its search for an optimal solution. Each dictionary has *m* basic variables. Let B denote the collection of indices from { 1,2,...,*n+m*} corresponding to the basic variables and let N = {1,2,...*n*} and B = {n+1, n+2,.... ...,*n+m*}, but this of course changes after the first iteration. Down the road, then current dictionary will look like this:

$$z = \bar{z} + \sum_{j \in N}^{n} \bar{c}_j x_j$$

$$x_i = \bar{b}_i - \sum_{j=1}^{n} \bar{a}_{ij} x_j \qquad i \in \text{B} \qquad (2.5)$$

Within each iteration of the simplex method, exactly one variable goes from non-basic to basic and exactly one variable goes from basic to non-basic. The variable that goes from non-basic to basic is called the *entering variable.* It is chosen with the aim of increasing z ; that is , one whose coefficient is positive: *pick k from* { $j \in$ N: $\overline{c_j} \geq 0$ }. Note that if this set is empty, then the current solution is optimal. If the set consists of more than on element (as is normally the case), then we have a choice of which element to pick. There are several possible selection criteria, we usually pick an index *k* having the largest coefficient (which again could leave us with a choice).

The variable that goes from basic to non-basic is called the leaving variables. It is chosen to preserve non-negativity of the current basic variables. Once we have decided that x_k will be the entering variable, its value will be increased from zero to a positive value. This increase will change the values of the basic variables:

$$x_i = \overline{b_i} - \bar{a}_k x_k \qquad i \in \text{B}$$

We must ensure that each of these variables remain non-negative. Hence, we require that:

$$\bar{b}_i - \bar{a}_{ik} x_k \geq 0 \qquad (2.6)$$

Of these expressions, the only ones that can go negative as x_k increased are those for which $\bar{a}_{ik}$ is positive; the rest remain fixes or increased. Hence, we can restrict our attention to these to those i's for which $\bar{a}_{ik}$ is positive. And for such an i, the value of x_k at which the expression becomes zero is

$$x_k = \frac{\bar{b}_i}{\bar{a}_{ik}}$$

Since we don't want any of these to go negative, we must raise x_k only to the smallest of all of these values.

$$x_k = \left[\min_{i \in B; \bar{a}_{ik} > 0} \right] \frac{\bar{b}_i}{\bar{a}_{ik}}$$

Therefore, with a certain amount of latitude remaining, the rule for selecting the leaving variable is *pick k from* $\{ i \in B : \bar{a}_{ik} > 0$ *and* $\frac{\bar{b}_i}{\bar{a}_{ik}}$ *is minimum*$\}$.

The rule just given for selecting leaving variables describes exactly the process by which we use the rule in practice. This is, we select one with the smallest value of the ratio $\frac{\bar{b}_i}{\bar{a}_{ik}}$. There is, however, another, entirely equivalent, way to write this rule we will often use. To derive this alternate expression we use the convention that 0/0=0 and rewrite inequalities (2.6) as

$$\frac{1}{x_k} \geq \frac{\bar{a}_{ik}}{\bar{b}_i}$$

Since we wish to take the largest possible increase in x_k we see that

$$x_k = \left(\max_{i \in B} \frac{\bar{a}_{ik}}{\bar{b}_i} \right)^{-1}$$

Thus, the rule for selecting the leaving variables is as follows: *pick l from* $\{ i \in B : \bar{a}_{ik} / \bar{b}_i \}$ is maximal**.**

The main different between these two ways of writing the rule is that in one we minimize the zero of $\bar{a}_{ik}$ to $\bar{b}_i$ whereas in the other we maximize the reciprocal ratio. Of course, in the minimize formulation one must take care about the sign of the $\bar{a}_{ik}$'s. In the remainder of this method we will encounter these types of ratios often. We will always write them in the maximize form since that is shorter to write, acknowledging full well the fact that it is often more convenient, in practice, to do it the other way.

2.6 Theory of Genetic Algorithm model

Genetic Algorithms (GA) possess several characteristics that answer the above planning problems and make them preferable to classical optimization methods. Genetic Algorithms are search procedures based on the natural genetics and natural selection. They combine the concept of the survival of finest with genetic operators extracted from nature to form a robust search mechanism. (Goldberg, 1989) identified the following differences between GAs and the traditional optimization methods:

1) GAs work with coding of the parameter set but not with the parameters themselves.

2) GAs search from a population of points, not a single point.

3) GAs use objective function information, not derivatives or other auxiliary knowledge.

4) GAs use probabilistic transitions rules, not deterministic rules.

Any nonlinear optimization problem without constraints is solved using genetic algorithms involving basically three tasks, namely, coding, fitness evaluation and genetic operation. The decision variables for the given optimization problem are first identified. These variables are then coded using binary coding into string like structures called chromosome. The length of the chromosome depends on the desired accuracy of the solution. The decision variables need not necessarily have the same sub string length. Corresponding fitness function is next derived from the objective function and is used in successive genetic operations. If the problem is for maximization, fitness function is taken as directly proportional to the objective function. The fitness function value of a string is known as the string's fitness. Once the fitness of each string is evaluated, the population is operated by three operators, reproduction, crossover and mutation for creating new population of points. In reproduction, good strings are selected to form a mating pool (Ulrich, Boldenhefer, 2004).

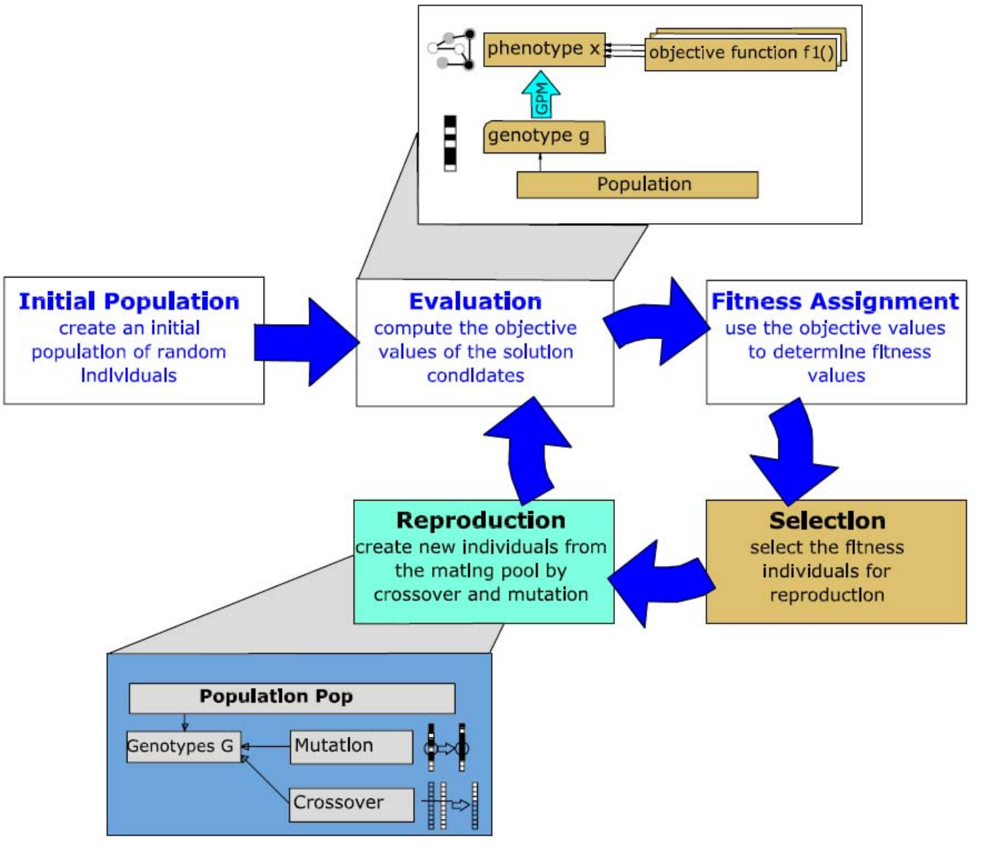


Figure 7 The basic cycle of genetic algorithm

There are many variation of GA, but the important features are general. The analogy with nature is established by creating a set of candidate solutions called a population. Each individual in a population is represented by asset of parameters that completely describe solution. These are encoded into chromosomes, which are, in essence, sets of character strings analogous to the chromosome found in DNA. Standard GA used a binary alphabet (characters are 0s or 1s) to forms chromosomes. For each generation, a measure how good each chromosome (or candidate solution) is calculated. This measure is called the *fitness* for each individual population. For each individual, its binary alphabet is decoded into parameter values, and then these values are substituted into a program that is used to calculate the fitness. This program may have virtually any form. Next, individuals are selected for "mating" to produce offspring, and this process is called *reproduction*. The reproduction is based on probabilities calculated from the individual's fitness value, which means that strings with higher value have a higher probability of participating in reproduction and hence of contributing one or more offspring to the next generation. Reproductions consist of *parent selection*, *crossover* and *mutation*. In crossover, genetic materials may be lost. The process of mutation, which is the occasional random alternation of the value of a string position, protects against such an irrecoverable loss. Crossover plays a primary role in GA, and the probability of crossover is generally set high, while mutation plays a secondary role, and the probability of mutation is set low.

a) String chromosomes

A string chromosome can either be a fixed-length tuple (Equation 2.7) or variable-length list (Equation 2.8). In the first case, the loci i of the genes g_i are constant and, hence the tuples may contain elements of different types G_i.

$$G = \{\forall (g[1], g[2], \ldots g[n]) : g[i] \in G_i \forall_i \in 1..n\} \tag{2.7}$$

This is not given in variable-length string genomes. Here, the positions of the genes may shift when the reproduction operations are applied. Thus, all elements of such genotypes must have the same type G_T.

$$G = \{\forall lists\, g : g[i] \in G_i \forall 0 \leq i < len(g)\} \tag{2.8}$$

String chromosomes are normally bit strings or vectors of real numbers. Genetic algorithms with such real genomes in their *natural representation* are called *real-encoded*. Today, more sophisticated methods for evolving good strings (vectors) of real numbers exist (such as Evolution Strategies, Differential Evolution, or Particle Swarm Optimization) than processing them like binary strings with the standard reproduction operations of GAs.

b) Fixed-length string chromosomes

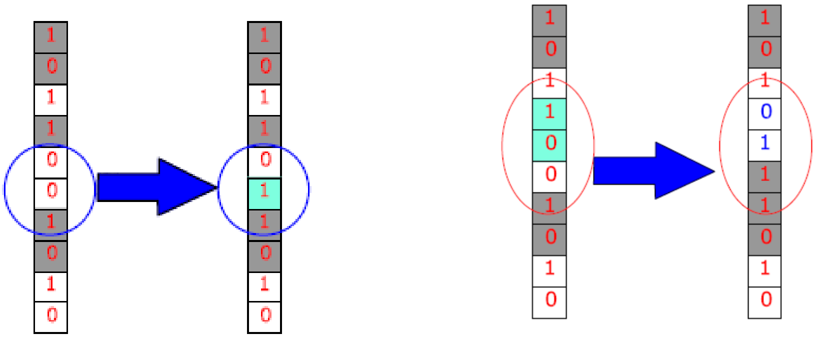
i) Creation

Creation of fixed-length string individuals means simple to create a new tuple of the structure defined by the genome and initialize it with random values.

$$create_{fl}() \equiv (g[1], g[2], \ldots g[n]) : g[i] = G_i \left[\left\lfloor \text{random}_u() * \text{len}(G_i) \right\rfloor\right] \forall_i \in 1..n \tag{2.9}$$

ii) Mutation

Mutation is an important method of preserving the diversity of the solution candidates. In fixed-length string chromosomes, it can be achieved by modifying the value of the genotype, as illustrated in figure 8. More generally, a mutation may change $0 \leq n < len(g)$ location in the string. In binary coded chromosomes, for example, the elements are bits which are simply togged. For real-encoded genomes, modifying an element g_i can be done by replacing it with a number drawn from a normal distribution with expected value g_1, like $g_i^{new} \sim N(g_1, \sigma^2)$.



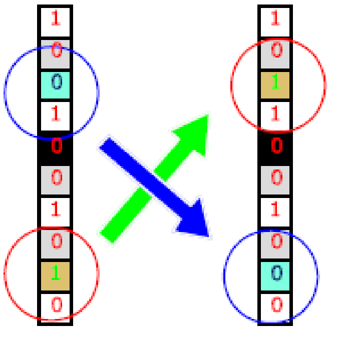
Change the Alle of one Genes (one Locus)

Change *n* Alleles of *n* Genes (*n* Loci)

Figure 8 Value-altering mutation of string chromosomes.

iii) Permutation

The permutation operation is an alternative mutation method where the alleles of two genes are exchanged. This, of course, makes only sense if all genes have similar data types. Permutation is, for instances, useful when solving problems that involve finding an optimal sequence of items, like the traveling salesman problem (Tomas Weise. 2008). Here, a genotype *g* could encode the sequence in which the cities are visited. Exchanging two alleles then equals of switching two cities in the route.

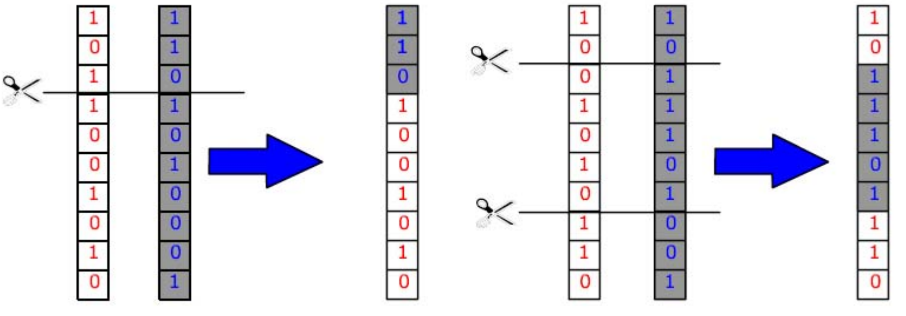


Exchange the alleles of two genes

Figure 9 Permutation applied to a string chromosome

iv) Crossover

Amongst all evolutionary algorithms, genetic algorithms have a recombination operation which is closest to the natural paragon. Figure 10 outlines the recombination of two string chromosomes, the so-called *crossover*, which is performed by swapping parts of two genotypes. When performing crossover, both parental chromosome are split at a randomly determined *crossover point*. Subsequently, a new child genotype is created by appending the first part of the first parent with the second part of the second parent. This method is called *single-point crossover* (SPX). In *two-point crossover* (TPX), both parental genotypes are split at two points, constructing a new offspring by using parts number one and three from the first, and the middle part from the second ancestor. The generalized form of this technique is the *n* point crossover, also called *multi-point crossover* (MPX). For fixed-length strings, the crossover points for both parents are always identical.



Single-Point crossover Two-point crossover

Figure 10 Crossovers (recombination) of fixed-length string chromosomes

2.7 Theory of Multi-Criteria analysis

Albeit the success of Expected Utility Theory (EUT) as the preferred technique for decision-making modelling after the Second World War, it has been recently criticized on the grounds of its single-attribute formulation. Among these studies we have (Gasson, 1973), (Harper and Eastman. 1980), (Cary and Holmes, 1982), (Perkin and Rehman.1994), (Willock et al., 1999) and (Solano et al. 2001). All these studies reveal the need of considering more than one objective when modelling farmers' decision-making process. Thus, it is plausible the assumption of the existence of a utility function with several attributes π, a_1, ... a_n, and that producers aim to maximize its expected value (Robinson, 1982). This is the core idea behind Multi-Attribute Utility Theory:

$$Max \quad E[U(\pi, a_1 ....a_n)] \tag{2.10}$$

If attribute $a_1..........a_n$ are not included in the utility function, the formulation becomes:

$$Max \quad E[U(\pi, \varepsilon)] \tag{2.11}$$

Where ε is error term that arises from omitting other attribute in utility function. As Robin point out (1982 : 374), the expected utility based on single attribute cannot accurately predict the producer's behaviour since there are other attributes involved in the decision-making process. In the same line, (Anderson et al. 1977 : 76) claim "money is not everything", therefore there are problems where it seems appropriate to consider other than monetary objectives. Acknowledging the convenience of including several objectives to simulate the producer's behaviour, we resort MAUT, an approach largely developed by (Keeney and Raiffa, 1976), to overcome the limitations of the single-attribute utility function. The multi-attribute approach attaches a cardinal value to each alternative, and considers the aggregate effect of all attributes. Thus, considering attributes from (Equation 2.11) we have:

$$U = U(r_1, r_2, ..., r_n) \tag{2-12}$$

Usually, the level of achievement of each attribute can be expressed mathematically as a function of the decision variables, this is, $r_i = f_i\left(\vec{X}\right)$. When a direction of improvement is assigned to each attribute we refer it as an objective. Thus, decisions under MAUT are made by maximizing U and responding to the set of objectives simultaneously followed by the producer.

Normally, decision variables $(\vec{X})$ included in mathematical models programming are considered as "activities" associated with crops or livestock to which a particular amount of inputs is assigned (i.e. an activity could be the surface devoted to wheat considering certain amounts of labour, agro-chemicals, etc.). This is the way to consider the direct relationship between the level of production and the amount of inputs used, once the real production functions (*f(v)*) are usually not available. In this sense it is possible to translate the level of each activity in the mathematical programming model, $(\vec{X})$, into a vector of inputs, $\vec{v}$. Thus, the attribute expressed as a function of activities, $r_i = f_i(\vec{X})$, can be formuled as well as a function of inputs used: $r_i = g_i\left(\vec{v}\right)$. Taking the example of the profit attribute, the new mathematical form as a function of inputs in classical micro economic theory is:

$$g_i(\vec{v}) = \pi(\vec{v}) = Pf(\vec{v}) - \sum_{i=1}^{n} p_{vi} v_i$$

Hence, from (Equation 2-11) we obtain:

$$U = U[g_1(\vec{v}), g_2(\vec{v}).....g_n(\vec{v})] = U(\vec{v}) \tag{2.13}$$

To seek the maximum profit, the first order condition implies:

$$\frac{\delta U(\vec{v})}{\delta v_i} = 0 \quad \rightarrow \quad MgU_{vi}(\vec{v}) = 0 \ \ \forall V_i \tag{2.14}$$

The former expression is a generalization of that proposed by the EUT and the Classical Economic Theory. Let's consider the EUT assumption of a single-attribute utility function, this is, the expected profit utility expression (Equation 2.13) takes the form:

$$U = U[\pi] = U[\pi(\vec{v})] \qquad (2.15)$$

This corresponds to the EUT approach for modeling the economic agents' behaviour since the maximization of $U[\pi(\vec{v})]$ resembles the maximization of the expected utility with profit as a single attribute. Moreover, assuming a linear utility function we get $U[\pi(\vec{v})] = \pi(\vec{v})$, but this is the case usually analyzed by the Classical Economic Theory, therefore the optimum used of input determined when:

$$MgU_{vi}(v) = \frac{\delta U(v)}{\delta v_i} = \frac{\delta[\pi(v)]}{\delta v_i} = \frac{\delta[Pf(v) - \sum_{i=1}^{n} P_{vi} v_i}{\delta v_i} = MgPV_{vi} - P_{vi} = 0 \quad \forall vi \qquad (2.16)$$

This EUT point of view, assuming a single-objective, could be considered as adequate when the inputs do not provide any other utility different from their contribution to the profit. However, as we will show later, this is not the case in the agricultural sector, where the inputs provide utility from other attributes different than profit. In spite of the interest of developing the analysis from expression (Equation 2.14), the main drawback comes from the elicitation of the multi-attribute utility function (Herath, 1981; Hardaker et al., 1997 : 162). In order to simplify this process, some assumptions are made about the mathematical features of the utility function.

The cardinal value of the utility function, obtained by adding the contributions of each attribute, enables us to rank them. The weighting of each attribute expresses its relative importance. In mathematical terms, the multi-attribute utility function (MAUF) takes the following form:

$$U = \sum_{i=1}^{n} w_i u_i(r_k) \qquad (2.16)$$

Where U is the utility value of alternative *k*,w_i is the weight of attribute *I* and $u_i(r_k)$ is the value of attribute *i* for alternative *k* . As pointed out above, the linear additive function adopted implicitly assumes that the weights (w_i) add up to 1.

Expression (2.16) in its simplest way takes the form:

$$U = \sum_{i=1}^{n} w_i(r_k) \qquad (2.17)$$

The former expression implies linear utility-indifferent curves (constant partial marginal utility), a rather strong assumption that can be regarded as a close enough approximation if the attributes vary within a narrow range (Edwards, 1977, Hardakar *et al.,* 1997 : 165). There is some evidence for the hypothesis in agriculture. Thus, (Huime and Hardakar, 1998) showed how the slope of the single- attributes utility function has little impact on the ranking of alternatives. From expression (Equation 2.17) and considering only one variable input we have:

$$U = \sum_{i=1}^{n} w_i g_i(v) \quad i = 1,....,n \tag{2.18}$$

The overall utility from factor *v* is the weighted sum of each factor partial utility function (FPUF), this is, the utility that is provided by the factor to each attribute. From this formulation the economic optimum implies:

$$MgU_v = \sum_{i=1}^{n} w_i \frac{dg_i(v)}{dv} = 0 \qquad i = 1,....,n \tag{2.19}$$

The former expression for one single product and one input can hardly be applied to the agricultural sector where the multi-output and multi-input processes are common. To handle the modeling problem we resort in the multi-criteria programming techniques. These techniques will allow us to obtain a linear additive MAUF. This utility function permits to reduce the complexity of the decision model to a single objective function (estimated MAUF) maximization programming. In this context, the marginal utility of the input v (*MgUv*) in the multi-attribute utility function is calculated from its shadow price. Using the amount of input as a parameter, we will be able to calculate the optimum to reach a shadow price equals to zero (*MgUv=0*).

In order to clarify the operational aspects of the MAUT model, we begin explaining the FPUFs ($g_i(v)$). These partial utility functions can exhibit increasing marginal utility ($dg_i(v)/dv > 0$) or decreasing one ($dg_i(v)/dv < 0$). As an example, let us consider the water input and two attributes: profit and leisure time. For the first case, as water allowance increases so does profit since farmers opt for more profitable crops, therefore we have an increasing water partial utility function, this is, $dg_{profit}(water)/dwater > 0$. On the contrary, for the leisure time attribute we have $dg_{leisure\_time}(water)/dwater < 0$, since more water intensive crops consume more labour. From the previous example we can see how, in the classical approach, the utility from one input is overestimated when considering profit as the only attribute. The results presented in this paper support this claim. Thus, considering the increasing or decreasing pattern of the partial utility functions, the usual assumptions of increasing utility function $\left(\frac{\delta U(\vec{v})}{\delta v_i} > 0\right)$ and concavity $\left(\frac{\delta^2 U(\vec{v})}{\delta v_i^2} < 0\right)$ cannot be assumed a priori within the multi-criteria context.

Variability of input use among producers

One central issue in this paper is the assumption of the variability of utility derived from the use of inputs among producers. These differences come both from the shape of the input partial utility function ($g_i(v)$), and the weights (w_i) attached to each attribute in the aggregate utility function. The Classical Economic Theory, considering $g_{profit}(v)$ as the single attribute, explains the differences of marginal productivity among the economic agents in terms of fixed resources allowance (natural resources, technology, etc.), and therefore the different variable inputs consumption at the optimum. Considering the case of irrigation water, both the mathematical programming models and the econometric models found in the literature clearly focus on structural factors (e.g. farm size and soil quality) to explain differences among producers on their water partial utility functions of the profit attribute, and thus, the difference in water and other inputs use.

We believe this is a partial view of the whole problem of simulating producer's decision-making processes. In a wider multi-criteria context we should consider also the pattern of the FPUFs of all relevant attributes, to continue with the aggregate analysis of them.

Whereas the differences on the FPUFs may be important for two different agricultural areas, these tend to be small for relatively homogeneous areas. Therefore, the significant differences on input use observed in these agricultural systems should be explained in terms of the objective weightings in the aggregate utility function. Let us consider, for example, the existence of two opposite type of producers: those with a profit maximizing behaviour, which implies intensive use of inputs, and those more conservative that prefer lower expected profitability but less variability of returns. They may have similar factor partial utility functions but different weights for each objective resulting in a very dissimilar use of inputs. Behind the variety of weights attached to each objective there are psychological, social and economic reasons, which vary considerably among farmers inside (and outside) any homogenous agricultural area. In this line, there are few studies comparing farmers' objective weighting, among them see for example (Sumpsi *et al*., 1997 and Berbel and Rodriguez. 1998).

Multi-criteria technique to elicit multi-attribute utility functions

The methodology adopted for the estimation of multi-attribute utility functions is based on the technique devised by (Sumpsi *et al.*, 1997 and Amador *et al*. 1998) with further modifications proposed by (Gómez-Limón *et al*., 2003). The objectives weighting obtained by this technique is consistent with the following separable and additive utility function (Dyer, 1977):

$$U = \sum_{j=1}^{n} \frac{w_j}{k_j} f_j(\vec{X}) \tag{2.20}$$

where k_j is a normalizing factor. Alternatively, the MAUF (Equation 2-19) can be expressed as:

$$U = \sum_{j=1}^{n} \frac{f_j(\vec{X}) - f_{j^*}}{f_j^* - f_{j^*}} \tag{2.21}$$

Thus, the utility function (Equation 2.20) is normalized by the difference between the ideal (f_j*) and the anti-ideal (f_{j^*})of the different objectives, and choosing the mathematical expression of the attributes as their utility function, $f_j(\vec{X})$, minus the anti-ideal (f_{j^*}).

The multi-criteria decision-making approach

The conceptual framework, regarding the methodological procedure followed in this paper, is displayed in Figure 11. As shown in this figure, the whole procedure comprises two distinct stages: (a) the stage of model formulation, where all necessary inputs are introduced into the multi-criteria model and (b) the stage of model application, where all solutions are obtained and then evaluated (D. Latinopoulos, 2007). At the first stage of the proposed methodology the initial step is to define sustain- ability criteria and to set the objective functions of the Multi-Criteria Decision-making Model (MCDM). Special attention is paid in setting the objective functions in order to represent all key factors of irrigated agriculture that may optimize the utility of a decision-maker. The next step is to select the decision variables and the agricultural and environmental constraints of the MCDM model. All the above-mentioned elements are introduced into the model, which is based on the multi-objective goal programming (MOP) technique.

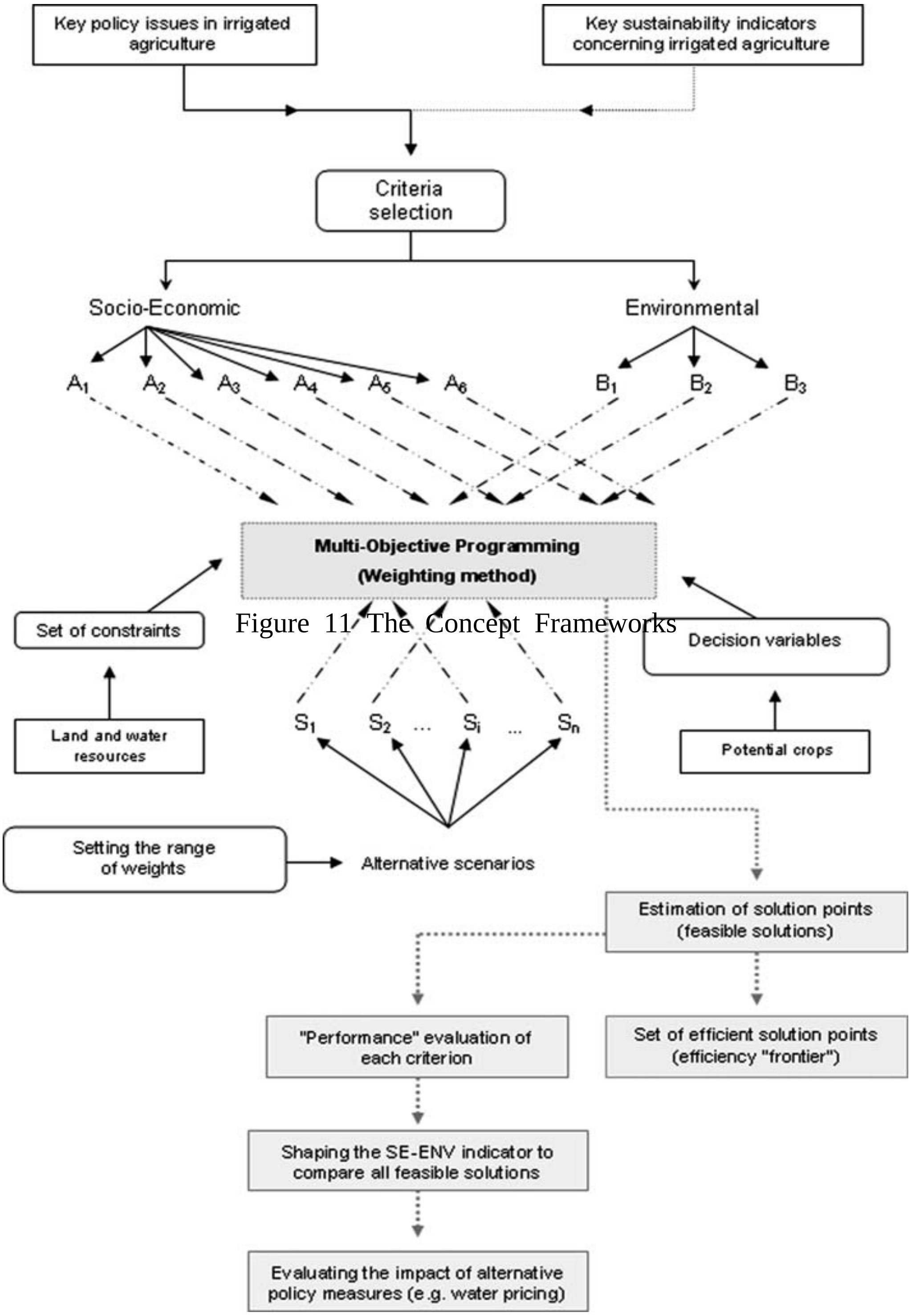


Figure 11 The Concept Frameworks

2.8 Related Researches

The study on related researches in this thesis is divided to three parts: i) linear programming model; ii) farmers' participation in water resource management; and iii) genetic algorithm model.

Related research of linear programming model for optimization search

Orlan H. Buller *et al*. (2000 : 1-15) was used a linear programming model to estimate the annual benefits and the crop acreage adjustment needed to achieve specified levels of efficiency with a flood irrigation system on a 160-acre field in Western Kasas. The model considered three irrigated crops; corn, grain sorghum, and wheat. There were several irrigation regimes for each crop; preseason irrigation only, limited irrigation, and full irrigation. Water requirements during prevegetative, vegetative, flowering, grain formation, ripening, and post ripening stages were considered for each crop. Different well yields at gallons per minute (GPM) were combined with different irrigation efficiencies to estimate the most profitable crop mix for a specified efficiency.
The results estimated by the economic model showed that for each 10 percent increase in irrigation efficiency, net income increased $1,284 annually for a 160-acre, flood irrigated field. This is equivalent to $8.03 per acre per year.

Related research of farmers' participation in water resource management

K. M. Chandran and G. Chackacherry (2004 : 77-79) discovered the Factors influencing farmer participation in irrigation management in the Cheerakuzhy irrigation project of Kerala in India, in which, farmer participation through water-user associations was measured, and it was linked to various socio-psychological and situational characteristics of the participants. Multiple linear regression analysis reveals that adequate, timely and equitable availability of water is cardinal to ensure effective farmer participation in the community irrigation projects. The study was carried out during 1996 among the farmers of the WUAs registered under Command Area Development Authorities (CADA) . The project has a command area of 978 ha, with 32 WUAs originally registered under it (CADA, 1997). Respondents (100) were members of six WUAs with valid registration, and were personally interviewed using a structured schedule. The socio-psychological determinants and the situational factors (independent variables) Farmer Participation Index (FPI) were calculated as suggested by Singh (1992). Relationship between the independent variables and the farmer participation index was worked out using multiple regressions (linear model) in MSTAT-C (ver. 1.41). A comparison of the data presented that the socio-psychological and situational variables (in total 13) explained about 44.5% of the variations in farmer participation. In particular, two socio-psychological characteristics-social participation and attitude towards participation, and two situational variables-availability of irrigation water and location of land on canal network, exerted a significant effect on farmer participation. Of these, irrigation water availability had an overwhelming influence (regression coefficient of 7.56) This is logical, since water availability in terms of adequacy, timeliness and equitability would be the main motivating factor for farmers to undertake irrigated farming and to involve in the activities of WUAs.

Davran K. M. (2005) used SWOT for analyzing participation of women farmer and women agricultural engineer to water management in Turkey. The model illustrative for this study was obtained from women farmers and women agricultural engineers by means of focus group interview. Three villages which have irrigated agriculture and located in Yuregir district were selected by simple basic probability sampling method for interview with women farmers. The result of the study indicated that in general, agricultural institutions, do not work in harmony with each other to provide coordination in province level for water management. On the other hand, institutions do not have any special program related water management for women. Irrigation activities are seen as men's work by the institutions, society and farmers. This is the main weakness for women participation to water management. Second important weakness is absence of extension activities of institutions related water management and women for rural people and women farmer. In fact extension program is one of the main duties in some institution and this is one of the important stringent factors. In addition to the measures mentioned above, some suggestions can also be made at institutional levels. Ministry of Agriculture is the most responsible institutions due to its active role in Turkish agriculture. This institution should be the pioneer for the empowerment of women in rural areas as a top governmental agency since governmental institutions' deeds are more acceptable than private sectors' in rural areas. On the other hand, number of women workers should be increased and existing women workers be it technical or social should be directed to rural areas or fields instead of office work. Once again, the attitude of these institutions against the women status in water management and in all roles should be changed with educational activities by government organizations.

Roy L. B. *el al.* (1999 : 250-253) presented the farmers' participation and the Hare irrigation project in sub-Saharan Africa. The study illustration was analyzed two farmers' associations which actives in the project area Chano Chelba and Chano Mile. The projects were not functioning well due to various technical and social problems e.g. poor operation and maintenance, weak farmers' association, inadequare training and visit programme and non-completion of the project itself due to the problem of land acquisition. For these questionnaires, the structural field interview technique was adopted for the study. The result was founded the total population in the command area of Hare project is approximately 4000. 55 per cent of the total population is female and the average number of person per family is six. The main ethnic groups in the study area are Gamo people, but there are immigrants from all the areas of southern nations nationalities, 78 per cent of the population are illiterate, the rest of the population have attended school up to 9. The farmers, in general, are below 50 years and they have spent about 5 to 45 years in farming activities. About 75 per cent of them are registered in the existing farmers' associations i.e. *Chano Chelba* and *Chano Mile*. The method of irrigation used by the farmers varies, some farmers use furrow irrigation only, others use wild flooding only and still others use the combination of the two. Those farmers, whose houses are nearer to their farming plots, irrigate their lands up to mid-night. But generally speaking, most farmers do not irrigate during night time because of the fear from mosquitoes, snake bites, hyenas and other wild animals. Sometimes as it is expected everywhere, some conflicts arise during irrigation period. Some farmers used to illegally divert the water from the canal for continuous irrigation. Then the other farmers will report this matter to the local 'water committees'. If a person is found guilty of such things, he will be charged up to 50 birrs as per the *'local water law'*. All the farmers will pay revenue to the Government. The revenue ranges from 20-30 birrs.ha^{-1}, which averages to 25 birr.ha^{-1}. The variation depends upon the efficiency of farm income by that farmer for that particular year. The success of any participatory management programme would depend upon attitudes of the site engineers. They have to be sympathetic to the farmers' problems, listen to their complains and be responsive to their needs. Apart from their own vocation, they have to learn to listen to the farmers and practice some social engineering. Few site engineers of proper caliber may be up to this requirement. The farmers' acceptance of participatory management and their desire to benefit from the system is of paramount importance. The agricultural extension programme, availability of agricultural inputs and access to the market for the farmers output would determine the success of any programme targeted to the farmers.

Related research of genetic algorithm model for optimization search in irrigation planning

K. Srinivasa R. and D. Nagesh K. (2004 : 163-176) presented that the genetic algorithm technique was used to evolve efficient cropping pattern for maximizing benefits for an irrigation project in India. Constraints include continuity equation, land and water requirements, crop diversification and restrictions on storage. Penalty function approach is used to convert constrained problem into an unconstrained one. For fixing genetic algorithm parameters the model is run for various values of population, generations, cross over and mutation probabilities. It is found that the appropriate parameters for number of generations, population size, crossover probability, and mutation probability are 200, 50, 0.6 and 0.01 respectively for the present study. Results obtained by genetic algorithm are compared with linear programming solution and found to be reasonably close. Cropping patterns obtained by both the methods are presented in Table II. Considerable deviations between the two methods are observed such as 15.78% for Sorghum (w) and 8.73% for Maize (w). Maximum benefits obtained by LP solution are 2.4893 Billion Rupees and 2.3903 Billion Rupees by GA. Irrigated area and net benefits obtained from GA have deviated from LP by 5.15 and 3.97%.

Alkoritmy (2000 : 293-300) at Slovak University of Technology explained advantage using genetic algorithms over deterministic method in optimal design of the water networks rehabilitation The described methods of optimal pipeline network rehabilitation were applied to the irrigation system Šala-Kolárovo (south-west part of Slovakia). This is one of the first irrigation facilities with large area coverage in Slovakia, with applied sprinkler irrigation and an underground pressurized water network. Its construction was completed at the beginning of the sixties and thus the whole facility is coming close to the end of its service life and hence it can serve as a suitable model for testing the proposed rehabilitation methods. The design of the system was substantially based upon the concept of hand-move laterals. Since this approach is now abandoned, its use is not producing required benefits. This is the reason why we have decided to review the rehabilitation proposals based on the concept of irrigation with non-specific hose-reel irrigators with an optimum output of 8,5 $ls^{-1}$and optimal inlet pressure 0,4-0,7 MPa (0,47-0,50 MPa was used as allowed minimal pressure in computations). In addition to that it is assumed that a battery of such sprinklers will be used, i.e. there will be a serial set of six machines. The original network is unable to comply with hydraulic requirements for such operation.

Kangrang A. and Chaleeraktrakool C. (2007 : 339-345) was used a fuzzy GA model determining varied irrigation efficiency of the Nong Wei irrigation project (in the North-east region of Thailand). There are four steps in developing fuzzy model: the first step of creating a fuzzy model is to transform the crisp inputs into fuzzy variable through the membership function. Next step is to apply the input membership functions and the rule bases to obtain the output membership functions. Finally, the process is defuzzification that a fuzzy set of output is converted into a single crisp value. The most common defuzzification method is the “centroid” evaluation, which returns the center of area under the curve. The adequacy of the fuzzy model is evaluated by considering the coefficient of determination (R^2) which defined on the estimation of irrigation efficiency. Three sequences of 26 years (1978-2003) seasonal flow, irrigated areas, water requirement records related evaporation and effective rainfall data during the dry season were considered for illustrating the application of the proposed approach. The results found that the fuzzy-Gas model can be used to obtain the irrigation efficiencies, given the total available water resources and requested irrigation-area. The Gas calibration provided the optimal condition of membership function in the values of 0.988 and 0.992. Thus, the proposed approach was given the irrigation efficiencies which were close to the actual irrigation efficiency.

Zhang B, *et al.* (2008 : 121-132) had studied of corn optimization irrigation model by genetic algorithms. The study was considered many factors which affect irrigation model, including irrigation water volume, crop water requirement, production function of irrigation water, rainfall, soil water balance, water sensitive index in different stages of crop growth, the grain market price, irrigation water price, minimum yield, irrigation cost etc. Using the experimental data from the experiment region plot in Libao and Shanxi (PR China), to solve and verify the irrigation-margin model to find out the optimum water distribution and maximal return from irrigation of summer corn under deficit and multi-constraints condition. Then a multi-constraints and non-linear optimization irrigation model based on the maximize profit of irrigation volume was set up in this illustrative application. The results showed that the model can solve the optimization irrigation problems of summer corn, and genetic algorithm has very perfect searching function, and the optimal solution of the model can be found very short time.

Bhaktikul, K. *et al.* (2004 : 1-11) conducted by comparison of Genetic Algorithm and Water Algorithm Scheduling and Monitoring (WASAM) model for real time water allocation in Song Phi Nong irrigation project, Thailand. The main purpose of this research is to apply a GA to the management of real time water allocation in Song Phi Nong Irrigation Project which covers area of 300,000 rai (48,000 ha) and 32 irrigation schemes. An optimization approach based on GA is described. The objective function is to minimize water shortage for the whole irrigation schemes and maintain the equitable manners on water allocation. The results of the GA were compared with WASAM model for water allocation in 3 cases; drought, normal and flood periods. It is concluded that GA offers the advantage over the WASAM model for water allocation in drought period to each irrigation scheme in a more equitable style. WASAM can operate for equitable water allocation only when normal stage not in the drought period.

Kuo, Sheng-Feng, Chen-Wuing Liu, and Shih-Kai Chen (2003 : 59-73) used genetic algorithm for comparative study of optimization techniques for irrigation project planning. The study presented three optimization techniques for on-farm irrigation scheduling in irrigation project planning: namely the genetic algorithm, simulated annealing and iterative improvement methods. The three techniques were applied to planning a 394.6 ha irrigation project in the town of Delta, Utah, for optimizing economic profits, simulating water demand, and estimating the crop area percentages with specific water supply and planted area constraints. The comparative optimization results for the 394.6 ha irrigated project from the genetic algorithm, simulated annealing, and iterative improvement methods were as follows: (1) the seasonal maximum net benefits were $113,826, $111,494, and $105,444 per season, respectively; and (2) the seasonal water demands were $3.03*10^3$ m^3, $3.0*10^3$ m^3, and $2.92*10^3$ m^3 per season, respectively. This study also determined the most suitable four parameters of the genetic algorithm method for the Delta irrigated project to be: (1) the number of generations equals 800, (2) population size equals 50, (3) probability of crossover equals 0.6, and (4) probability of mutation equals 0.02. Meanwhile, the most suitable three parameters of simulated annealing method for the Delta irrigated project are: (1) initial temperature equals 1,000, (2) number of moves equal 90, and (3) cooling rate equals 0.95.

Cai X., McKinney C. D., and Lasdon L. S., (2001 : 667-676) solved nonlinear water management using a combined genetic algorithm and linear programming. This genetic algorithm and linear programming approach is applied to two non-linear models: a reservoir operation model with non-linear hydropower generation equations and non-linear reservoir topologic equations, and long-term dynamic river basin planning model with a large number of non-linear relationships. For smaller instances of the reservoir model, the CONPT2 non-linear solver was more accurate and faster, but for larger instances, the GA and LP approach found solutions with significantly better objective values. The multi-period river basin model was much too large to be solved in its entirety. The complicating variables were chosen there so that, when they were fixed, each period model was linear, and these models could be solved sequentially. As in most GA applications, initial rapid convergence was followed by a long, slow but steady improvement of the objective. However, solutions within 5% of the final value were found early in the process, and computation time did not increase rapidly with problem size for the methodology parallelizes very well, since the problems of finding the fitness of each individual were independent of one another and may be solved simultaneously. A parallel implementation would almost surely result in speedups which were proportional to the number of processor.

Related research of Multi-Criteria Optimization

Kurt, F., Milan K. and Maja Z. A., (2007) integrated a set of simulation models with data bases, GIS, and optimisation and DSS tools. The fully web-based management information system was being applied to several river basins ranging from 240 to 18,000 km^2 in size around the Eastern and Southern Mediterranean. All these river systems were characterised by varying levels of water scarcity, allocation conflicts, and pollution problems. The system was integrated a cascade of models, embedded in a framework for participatory multi-objective, multi-criteria optimization. Models include a dynamic water resources (network) model with a daily time step, coupled to one or more aquifers. The model performed economic evaluation of allocation scenarios including environmental water allocation and the reliability of supply/demand; a dynamic rainfall-runoff model with built-in automatic calibration that provides simulated flow from engaged sub catchments; an irrigation water demand model; a basin wide water quality model with economic evaluation including environmental and recreational benefits; and tools for multi-criteria techno-economic optimization combining satisfying and reference point methods.

José, A. Gómez L., Laura R. and Manuel A. (2003) explained Multi-criteria analysis of factors use level: The case of water for irrigation scheme in North-western Spain. The optimal input use condition was determined by the assessment of “multi-attribute utility” and “multi-attribute marginal utility”. The model was a generalization of the single-attribute expected utility theory and developed was further implemented in an empirical application that studies water for irrigation use as a particular case. Results showed how multi-attribute utility functions elicited for a sample of 52 irrigators explained differences on irrigation water use in relative homogenous agricultural systems, albeit exhibiting similar water partial utility functions. It seems that these differences come from the dissimilar weights that farmers attached to each attribute in the aggregate utility function.

It is conclusively, an alternative portion for seeking the overall problems for sustainable irrigation development by using genetic algorithm model, which is the most technique possess several characteristics that answer the planning problems and make them preferable to classical optimization methods. Genetic Algorithms are search procedures based on genetics and natural selection. The solution obtained by GA for irrigation planning can be further refined for a number of factors such as penalty function values, mutation and crossover probabilities, generation and population (Ulrich, Boldenhefer, 2004)

Hence, the proposed LP and GA model has applied to find the optimal crop pattern in dry-season (November-April) of the Nam Houm irrigation scheme, Vientiane capital, Lao PDR. Constraints include continuity equation, available land area, available water resource, farmer participation in water resources management and cost of products were used in GA model.

The records of seasonal flow from the reservoir, requested and actual implementation of irrigation area, crop water requirements, evaporation, percolation, effective rainfall and varying irrigation efficiency were used for this research.

Chapter 3

Research Methodology

This chapter introduces the tools for data collection, thee methodology of data collection and the procedure for analysis modeling, which consists of the following details:

1. Study Area
2. Population and random sampling
3. Tools for data collection and analysis
4. Method of data Collection
5. Statistic of data analysis and research
6. SWOT multiple criteria
7. Research methodology chart
8. Procedure of analysis of the Mathematical Model for estimating varied irrigation efficiency
9. Procedure of Analysis of developed LP Model for irrigation planning
10. Procedure of analysis of the optimization for cropping planning using GA model
11. Methodology and Approach
12. Illustrative application

3.1 Study Area

Nam Houm is a reservoir irrigation system located at Naxaythong District in Vientiane Capital, Lao PDR. Its irrigated area is covered by 2 districts – Naxaythong (where most of the area is located) and Xaythani (end of the Main canal). The location map for the system is in figure 12. It has 21 beneficiary villages, 19 villages in Naxaythong and 2 village sin Xaythani). The beneficiary households in Naxaythong are all Lao Loum while the beneficiaries in Xaythani are composed of Lao Sung and Lao Loum.

The Nam Houm Irrigation Scheme (NIS) has an estimated irrigation service area of 4,200 hectares during wet season and 1,800 hectares during the dry season.

The reservoir and main canal were constructed in 1977 to early 1982 through government funds and free labor provided by villages in Naxaythong and government staff of the different Ministries in Vientiane Capital under the supervision of the Department of Irrigation (DOI) of the Ministry of Agriculture and Forestry. The design was prepared by Vietnamese Irrigation Engineers. In 1990 to 1994, the Mekong Secretariat (now known as the Mekong River Commission) supported the construction of the N1 secondary canal which benefits more than 400 hectares. The construction work was contracted to an Italian Construction Company and was supervised and monitored by a Project Officer from the Mekong Secretariat and Project Personnel composed of DOI Staff.

The map of the irrigation system is presented in figure 12 below:

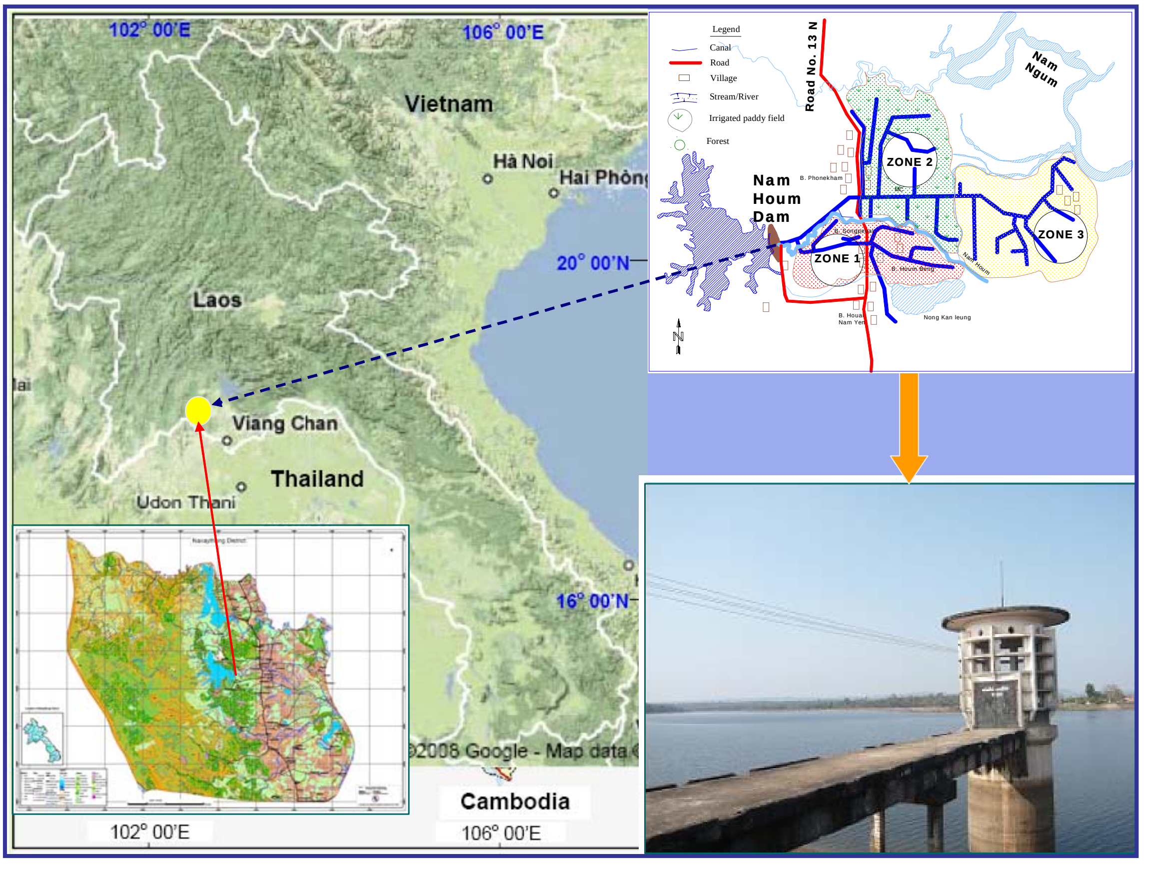


Figure 12 Location of Nam Houm Irrigation Scheme

3.2 Population and Random Sampling

The population and random sampling is formulated total five groups of the sampling: i) the local authorities of the beneficiary villages in the project such chief of the villages, women, senior in the village totaling 21 persons; ii) all chairmen and blocks leader of WUA/WUG, accountants; iii) the farmers and water master, which have cultivated area in the head of the canal (main or secondary), totaling 10 persons; iv) the farmers and water master, which have cultivated area in the middle of the canal (main or secondary) , totaling 10 persons; and v) the farmers and water master, which have cultivated area in the tail of the canal (main, secondary or tertiary) , totaling 10 persons.

3.3 Tools for data collection

1. Equipments for data collection
   - Rain gauge
   - Percolation test
   - Water velocity measurement
   - Evaporation

- Computer notebook

2. Tools for primary data collection

- Preparation the questionnaire such: Technical information form, socio-economic information forms, institutional information forms etc.

3.4 Method of Data Collection

1. Primary data collection

Using questionnaires for interviewing of the groups sampling such as the group of farmers, water masters, block leaders which are formulated above. The interview will identify major factors as following:

i) Institutional factors

- Interview the groups sampling and review the government policy to the WUA;

ii) Technical factors

- Interview the technical staffs and review the design and construction drawings of the scheme.

iii) Socio-Economic factors

- Interview with public and private stakeholders
- Interview with individual farmers of the group sampling

2. Secondary data collection

- Collection all technical data of the scheme such as Design Drawings, operation and maintenance reports, the historical of water delivery and distribution and cultivated area in wet and dry season in several year, the statistic of farmers' participation in water resource management and irrigation management and related data of the project backgrounds.

3.5 Statistic of data analysis and research

The statistic of data analysis will use the technique tools of SWOT analysis for describing the factors of farmers' participatory in water resource management and irrigation management, for the other factors the author will use optimization technique such linear programming model, genetic algorithm model for analyzing and solving the above problems.

3.6 SWOT multiple criteria

SWOT analysis Strengths, weaknesses, opportunities and threats analysis is a useful tool for the planning development and decision-making and has widely been applied to environmental planning and water resource management. The acronym SWOT corresponds to the initial of the included parameters: SWOT. Strengths and weaknesses are factors of the system (internal issues), while opportunities and threats are factors of the external environment (external issues). In other words, a SWOT analysis helps to find the best match between water resources management trends (opportunities and threats) and internal capabilities and facilitate a strategic approach to administration (Richards, 2001). Concerning the application of SWOT analysis, it is necessary to minimize or avoid both weaknesses and threats. Weaknesses should be converted them into strengths (Danca, 2000). Likewise, threats should be converted into opportunities. In addition, strengths and opportunities should be matched to optimize the water resources management of the NIS.

- Recording of the present situation in the research area.
- Examination of the possible acts for the facing of the problems that were detected.
- Analysis of the opportunities and the threats that come from external environment.
- Analysis of the strengths and the weaknesses of the system and finally.
- Categorizing of the proposed actions.

INTERNAL		EXTERNAL	
Strengths	Weaknesses	Opportunities	Threats

And here's a third option for structuring SWOT analysis that will be appropriate for a large initiative that requires detailed planning or many alternatives in Nam Houm Scheme.

	STRENGTHS 1. 2. 3. 4.	WEAKNESSES 1. 2. 3. 4.
OPPORTUNITIES 1. 2. 3. 4.	Opportunity-Strength (OS) Strategies Use strengths to take advantage of opportunities 1. 2.	Opportunity-Weakness (OW) Strategies Overcome weaknesses by taking advantage of opportunities 1. 2.
THREATS 1. 2. 3. 4.	Threat-Strength (TS) Strategies Use strengths to avoid threats 1. 2.	Threat-Weakness (TW) Strategies Minimize weaknesses and avoid threats 1. 2.

3.7 Research methodology chart

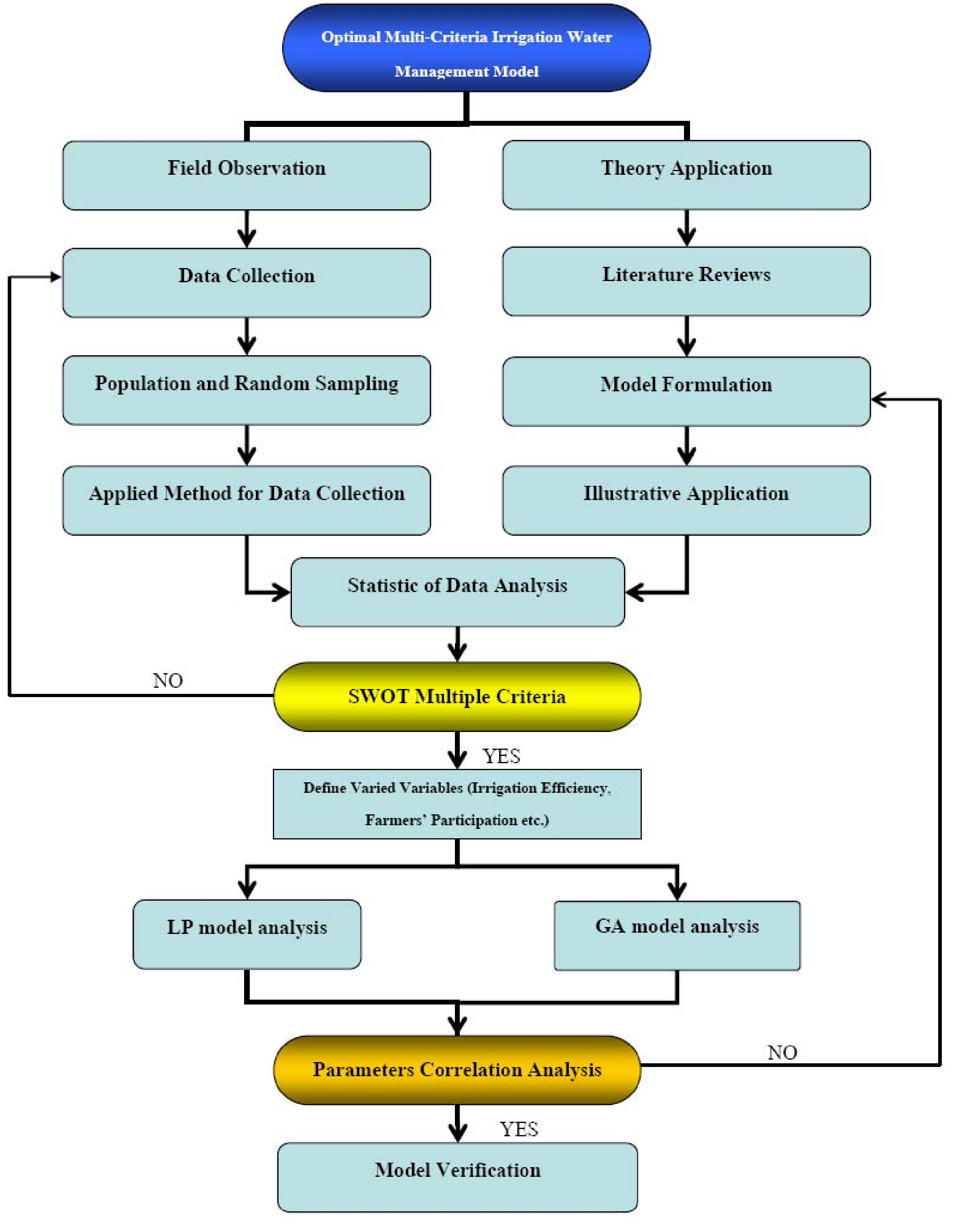


Figure 13 Research methodology chart

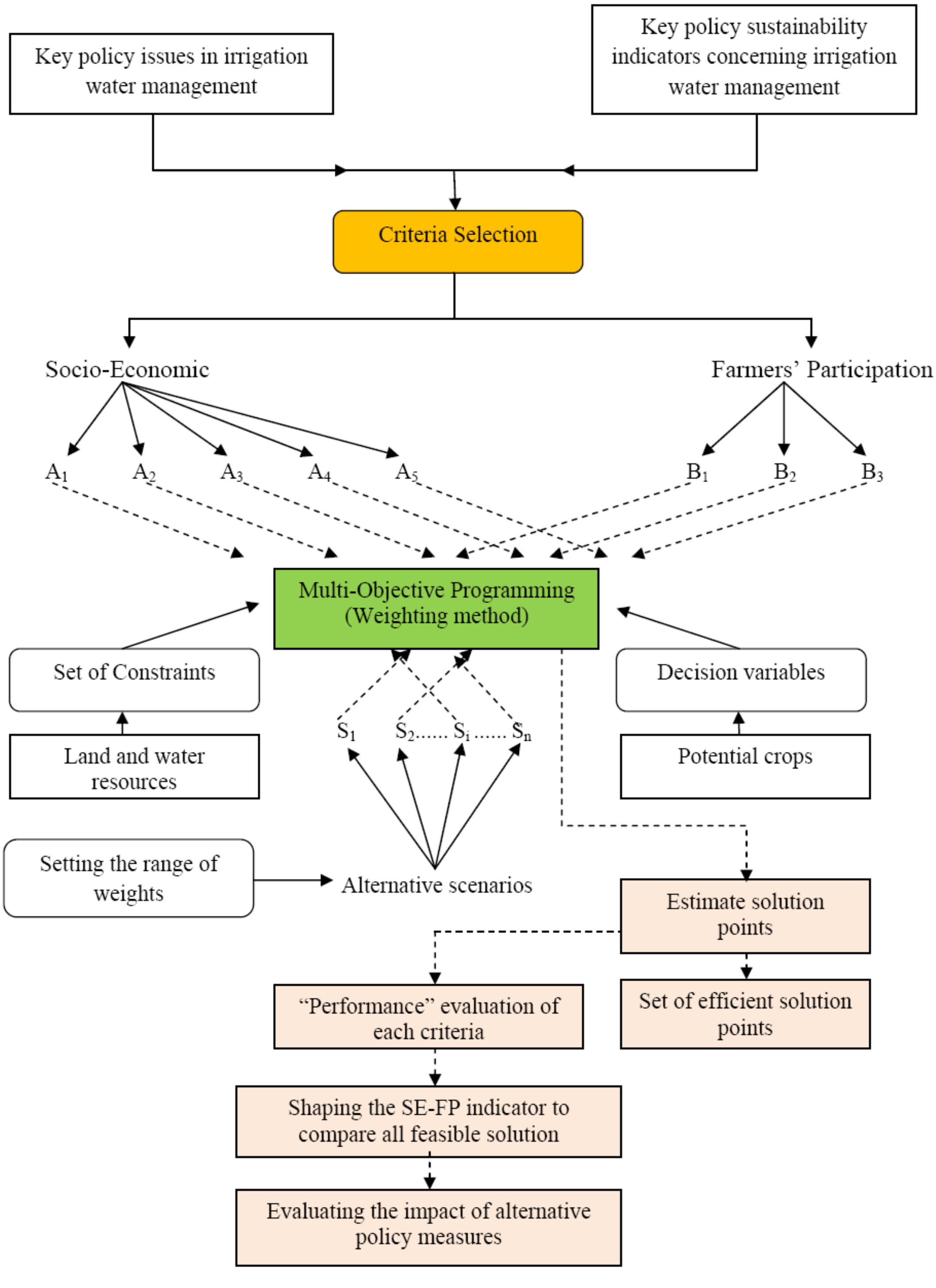


Figure 14 Multi-objective frameworks

3.8 Procedure of analysis of the Mathematical Model for estimating varied irrigation efficiency

Introduction

Irrigation Efficiency is an obvious issue for agricultural development. Improvement irrigation efficiency not only can improve equity in water distribution but also can minimize the gap between crop water requirements and actual water use. In consequence, it will lead to determine the effectiveness of water use and lead to improve the livelihood people. Generally, irrigation efficiency is the overall system efficiency which affecting by conveyance, distribution and paddy field application. Most previous studies mainly analyzed field level efficiencies, and considered the irrigation efficiency as a constant value for all season (DOI report, 2007), (MRCS annual report, 2006). However, there are not enough reliable to estimate irrigation efficiencies and actual water use.

However, it is likely that the efficiencies tend to vary due to the uncertainty of water resources. The participation of stakeholder in water resources management is main effect of irrigation efficiencies (Kanrang, A. and Chaleeraktrakoon, C., 2007). Hence, participation of stakeholder in water resources management is important factor for estimating irrigation efficiency. A multiple regression is the mathematical relationship which describes a system by a set of variables and a set of equations that establish relationships between the variables. The values of the variables can be practically anything such as mathematical relationships between the advance time and distance from the stream end using regression function for analysis (Sajid M *et all*., 2003). The multiple regressions can be useful tool to determine the irrigation timing as a function of environmental and operational conditions (e.g. working pressure, air temperature, relative humidity, etc.) in order to minimize evaporation and drift loss (Oretega J. F. *et all.*, 2000). A mathematical model is search and optimization techniques based on linear and non-linear multiple equations. The mathematical model is a method for searching the memberships of functions and it was applied to solve the optimal solution of water resources and varied irrigation efficiencies problems (Pulido-Calvo I.*et all*, 2003 : 422-431). In addition, this mathematical model is relatively easy to explain and understand. This study thus proposes the mathematical model for finding the varied efficiency which corresponding seasonal inflow, farmer participation in water resources management, land area cultivation in the previous season and cost of crop production. The relationship between input and output variables is defined from a mathematical formula, according to human processes in thinking and decision

Model Formulation

Multiple regression (or, more generally, "regression") allows researchers to examine the effect of many different factors on some outcome at the same time. The general purpose of multiple regressions is to describe about the relationship between several independent or predictor variables and a dependent variable. For some kinds of research questions, regression can be used to examine how much a particular set of predictors explains differences in some outcome.

Thus, multiple regressions are usually composed by variables, which are abstractions of quantities of interest in the described systems, and operators that act on these variables, which can be algebraic operators, functions, differential operators, etc. If all the operators in a mathematical model present linearity, the resulting mathematical model is defined as linear. A model is considered to be nonlinear otherwise.

In order to account for any uncertainty on seasonal inflow, land area of cultivation, product cost and farmer participation in water resources management, the mathematical model by using linear and non-linear multiple equations for estimating varied irrigation efficiency. System inputs include the seasonal inflow, seasonal requested area, participation of stakeholders and product cost. Output is the seasonal irrigation efficiency from various seasonal operation factors.

There are three steps in developing mathematical model as the following:

The first step of creating a mathematical model is to test the variables input. If all variables in the mathematical model present linearity, the resulting mathematical model is defined as linear and if otherwise will be considered as non-linear. The mathematical formula for estimating variables is:

$$y_{ij} = a * X_1^{b_1} * X_2^{b_2} * X_3^{b_3} * ..... * X_m^{b_m} \qquad (3.1)$$

where y_{ij} is estimated irrigation efficiency of scenario *i* during the season *j*; *a* and b_i are parameters of multiple functions during the scenario *i* $(i=1,2,3\ldots m)$; X_1 is seasonal variable of total irrigated areas; X_2 is seasonal variables of farmer participation in water resources management; X_3 is seasonal variable of inflow; X_4 is seasonal product cost; and X_m is seasonal variables input for estimating parameters of the mathematical model of scenario *m*.

The secondly, the parameters of multiple functions were used to estimate irrigation efficiencies on each historical data. The actual historical data of irrigation efficiency will be presented in the next section.

Finally, the mathematical model was evaluated by considering the coefficient of correlation (r) and coefficient of determination (R^2) which define base on the actual irrigation efficiency and estimated irrigation efficiency from the model as:

$$R^2 = \frac{\left(\sum_{j=1}^{n} e_j \hat{e}_j - n\bar{e}_j \bar{\hat{e}}_j \right)^2}{\left(\sum_{j=1}^{n} e_j^2 - n\bar{e}_j^2 \right)\left(\sum_{j=1}^{n} \hat{e}_j^2 - n\bar{\hat{e}}_j^2 \right)} \qquad (3.2)$$

where e_j is the estimated irrigation efficiency of the scenario during season j which calculated using mathematical model, $\hat{e}_j$ is the actual irrigation efficiency of the scenario during season j which calculated from irrigated area, participation of stakeholder, product cost and value of available water, $\bar{e}$ and $\bar{\hat{e}}$ are respectively the average of above mentions and n is the number of annual historic data.

Generally, irrigation efficiency is the overall system efficiency which affecting by conveyance, delivery and field application efficiencies (Phengphengsy F. and Hiroshi O., (2006). The actual irrigation efficiency of the system can be computed by following equation:

$$\hat{e}_j = 100\left(\frac{V_{net}}{V_{gross}}\right) \tag{3.3}$$

where: V_{net} is the net volume of crop water requirement (m^3), V_{gross} is the gross water diverted from the source to the conveyance system (m^3).

The net value of crop water requirement is computed as:

$$V_{net} = \sum_{j=1}^{j}\sum_{k=1}^{K} CWR_{jk} X_{jk} \tag{3.4}$$

$$CWR = WR_{vu} \text{ x Stage of crop development} \tag{3.5}$$

where: CWR_{jk} is crop water requirement rate of crop k during season j (mm.ha-1), X_{jk} is cropped area of crop k during season j(ha), WR_{vu} is crop water requirement ($mm.day^{-1}x10^{-3}$) of crop type u at the day v.

3.9 Procedure of Analysis of developed LP Model for Irrigation Planning

Introduction

An allocation of limited available resources is one of the classical problems in water resources management. In particular, given the total available resources for example water, soil, land area and manpower, one would like to know what proportion of the available resources should be given to each considered crop in an irrigation project in order to maximize the total profit of agricultural activities. With optimization techniques available; such as Linear Programming (LP), Dynamic Programming (DP) and Genetic Algorithm (GA), it is LP model that is more popular because of the proportionate characteristic of the allocation problems. The formulation of the LP model to the problems usually assumes that crop water requirement and crop yield of all soil types in the considered project be homogeneous value for all seasons. Unfortunately, the assumption often leads to serious error in the optimal solution of the crop pattern.

In consequence, before starting of each irrigation season, an operation and maintenance staff of the irrigation scheme should prepare appropriately of irrigation planning to ensure that required total of land-area from the farmers for each seasonal cultivation and how much water to be distributed into paddy fields. Also the irrigation facilities and structures should monitor time to time. For this reason, the repair of irrigation canals and structures is necessary. Oppositely, the farmers need to have the optimum cropping pattern which will maximize the economic return.

Often, most irrigation projects lacked satisfactory tools for finding the optimal crop pattern that considering crop yield from crop water requirement and appropriate physical soil type. The crop yield is usually affected by crop water requirement and physical soil type which suitable for cultivation of each crop. As a result the obtained pattern is inappropriately with soil type, so consequences are increasing production cost, using chemical fertilizer and pesticide and increasing pollution (Bos M. G and Nugteren J. 1990).

In accordance with the above constraints issued, the project needs to improve irrigation planning before starting of each irrigation season in order to maximize the total profit of agriculture activities.

A linear programming is an optimization technique which widely used to allocate the limited water resources because of the proportionate characteristic of allocation problem (Haouari, M and Azaiez, M. N., 2001). Furthermore, the LP is easy to apply with the problem of irrigation planning using several available programs.

The maximization benefit was set as the objective function based on the resources constraints. The constraint functions are linear equation for finding optimum crop pattern when given available water (Panda, S. N., Khepar, S. D. and Kuashal, M. P., 1996). For finding optimum crop water requirement when given available water (Salman, A. Z., *et all*., 2001).. A different portion price of irrigation water is considered in constraints of LP model (Sethi, L. N, *et all*, 2002).

The purpose of this study is to propose an allocation LP model that can take into account multi-functioned land area and multi-crop water requirements. The multi-functioned character of the irrigation project will be represented by dividing each crop water requirement and paddy fields into several crops and sub- areas based on suitable soil type for cultivation crop.

Model Formulation

The linear programming is used as a based model for finding optimal crop water requirements and optimal seasonal crop pattern. The model will be formulated to maximize benefit subjected to the limited resources on available seasonal water and suitable soil types of each crop. The obtained cropping pattern can be used for seasonal planning which considering the multi-functioned characters of paddy fields.

The objective function of the model can be presented as:

$$MaxZ_j = \sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K} NB_{hik} X_{hijk} \qquad (3.7)$$

where Z_j is the gross benefit of the scenario during the season *j*, *h* is sub-area index of the scenario (*h=1,2,3,….H)*, *i* is soil type index (*i=1,2,3…I)*; *j* is seasonal index *j*, *k* is crop type (*k=1,2,3…K)*, NB_{hik} is net benefit of crop *k* in sub-area *h* for soil type *i* (Kip.ha^{-1}), and X_{hijk}, is irrigated area of crop *k* in sub-area *h* for soil type *i* during season *j* (ha).

The constraints of the model can be divided into two categories including water constraint and land area constraint. The water constraint considered the irrigation efficiency from the mathematical model, due to the varied irrigation efficiencies were closed to the actual irrigation efficiencies all series. Therefore, the overall water efficiency of the Nam Houm irrigation scheme was used for mono-functioned character, which can describe as:

$$E_{overall} = \frac{SWR - ER}{WDF} x100 \qquad (3.8)$$

where $E_{overall}$ is overall efficiency of the irrigation project, *SWR* is total scheme water requirement(m^3), *ER* is effective rainfall (m^3), and *WDF* is water delivery to the paddy fields.

$$SWR = \sum_{u=1}^{U} \int_{v=1}^{V} WR_{vu} x A_{vu} \qquad (\mathrm{m}^3) \qquad (3.9)$$

$$WDF = (I * E_c + N) - (D + C) \quad (\mathrm{m}^3) \qquad (3.10)$$

where: *I* is intake water through main canal (m^3), E_c is canal efficiency, *N* is total natural flow entering command area (m^3), *D* is drain water to sink outside without reuse or non-utilizable water supply (m^3), *C* is committed flow to other areas (e.g legally and conventionally committed outflow from command areas to outsides (m^3)), WR_{vu} is crop water requirement (mm.day^{-1}x10^{-3}) of crop type *u* at the day *v*, A_{vu} is actual cultivated area (m^2) of crop type *u* at the day *v*.

For Paddy:

$$WR_p = ET_o * K_c + P + L_P \qquad (3.11)$$

For Non-paddy Crop:

$$WR_N = ET_o * K_c \qquad (3.12)$$

For Fish pond

$$WR_p = ET_o * K_c + P \qquad (3.14)$$

where ET_o is potential or reference evapo-transpiration in mm/day, K_c is crop coefficient (dimensionless), *P* is percolation in mm.day^{-1}, and L_P is land preparation in mm.day^{-1}.

For practical water requirement for fish ponds are calculated in the same way as water requirement for crops. A fish pond is comparable with an evaporation pan therefore one K_c value should be used throughout the year. It is recommended to use a K_c value of 1.2 for calculating requirement for fish pond (MRCS annual report, 2007).

The net crop water requirement is not greater than the total available water of the irrigation scheme multiplying the irrigation efficiency of irrigation project, which described as:

$$\sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K}\sigma_{hijk}X_{hijk} \le E_{overall}Vd_{j} \quad (3.15)$$

$$\sigma = WR_{vu} \text{ x Stage of crop development} \quad (3.16)$$

where σ_{hijk} is crop water requirement rate of crop k in sub-area h for soil type i during season j (mm.ha^{-1}), Vd_j is total available water of the irrigation system during season j (Mm^3), and $E_{overall}$ is the overall irrigation efficiency of the irrigation project.

The seasonal available water of each zone (q_{hj}) is calculated by multiplying the net available water of the irrigation system with a proportion of each zone area and total area (T_j), which presented as:

$$q_{hj} = E_{overall}Vd_{j}\left(\frac{X_{hj}}{T_{j}}\right) \quad (3.17)$$

$$\sum_{i=1}^{I}\sum_{k=1}^{k}\sigma_{hijk}X_{hijk} \le q_{hj} \quad (3.18)$$

For the land constraint, the summation of all zone area is not greater than the available total area of scenario during season j; which described as:

$$\sum_{h=1}^{H}X_{hj} \le T_{j} \quad (3.19)$$

In each zone divided into several sub-areas suitable to soil type. The total land area of all soil type is not larger than the available area of the zone, which presented as:

$$\sum_{i=1}^{I}\sum_{k=1}^{K}X_{hijk} \le X_{hj}; \quad \text{for h=1,2,3....H} \quad (3.20)$$

The net irrigated area of all crops is not greater than the land area of each soil type. The irrigated area of each crop is not larger than the suitable area for its cultivation. These constraints are of the following form:

$$\sum_{k=1}^{K}X_{hijk} \le X_{hij}; \quad (3.21)$$

for h= 1,2,3,…H and i = 1,2,3…I

$$X_{hijk} \le S_{hijk}; \quad (3.22)$$

for h= 1,2,3,…H and i = 1,2,3…I and k= 1,…K

$$X_{hijk} \ge 0 \quad (3.23)$$

where S_{hijk} is amount of suitable land for the cultivation of crop k in sub-area h for soil type i during season j .

In order to consider the multi-functioned character of paddy field of the suitable soil type for cultivation each crop, the zone area is divided into several suitable soil types (see figure 16).

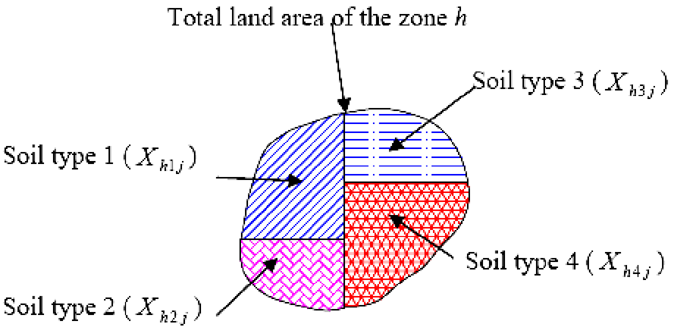


Figure 15.The suitable soil type for the cultivation in a zone area

3.10 Procedure of analysis of the optimization for cropping planning using GA model

Introduction

An allocation of limited available resources is one of the classical problems in water resources management. In particular, given the total available resources for example water, soil, land area and manpower, one would like to know what proportion of the available resources should be given to each considered crop in an irrigation project in order to maximize the total profit of agricultural activities. With optimization techniques available; such as Linear Programming (LP), Dynamic Programming (DP) and Genetic Algorithm (GA), it is LP model that is more popular because of the proportionate characteristic of the allocation problems. The formulation of the LP model to the problems usually assumes that crop water requirement and crop yield of all soil types in the considered project be homogeneous value for all seasons. However, GA is alternative technique required to find optimal solution several cases.

Genetic algorithms (GAs) are based on the theory of Darwinian evolution. It is a way to solve complex problems with little information and no need of an exact solution. The result of GA calculation is always an approximate value which best meets the objective function. GA contains stochastic functions which mean that every run produces different results. It can be used for linear or nonlinear problems, with constraint or without. It maintains a population of solutions which are encoded in chromosomes. During reproduction new population members are created by recombination and mutation.

Thus, GA is another search technique that applied to search optimal rule curves of the reservoir system (Chen, 2003; Chang *et al*., 2005; Adib and Tagavifar, 2010). The best part of GAs model is that it can handle any type of objective function of the search. In addition, the applied GAs can handle any condition of reservoir simulation such as initial reservoir capacity and the period of inflow record. The appropriate objective function for searching the curves is average water shortage. Also, a smoothing function constraint is required to include into the proposed GAs for fitting the rule curves (Kangrang and Chaleeraktrakoon, 2007). However, there are limited conditions on these search techniques such as the complicate process of GAs.

The GA model will be applied to find the optimal crop pattern in dry-season (November-April) of the Nam Houm irrigation scheme, Vientiane capital, Lao PDR. The maximization benefit was set as the objective function based on the resources constraints. Constraints include continuity equation, available land area, available water resource, farmer participation in water resources management and cost of products were used in GA model. The records of seasonal flow from the reservoir, requested and actual implementation of irrigation area, crop water requirements, evaporation, percolation, effective rainfall and varying irrigation efficiency were used for this illustrative application.

Model Formulation

The GA is used as a based model for finding optimal crop water requirements and optimal seasonal crop pattern. The model will be formulated to maximize benefit subjected to the limited resources on available seasonal water and suitable soil types of each crop. The obtained cropping pattern can be used for seasonal planning which considering the multi-functioned characters of paddy fields.

The objective function of the model can be presented as:

$$MaxZ_j = \sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K} NB_{hik} X_{hijk} \qquad (3.24)$$

where Z_j is the gross benefit of the scenario during the season *j*, *h* is sub-area index of the scenario (*h=1,2,3,….H*), *i* is soil type index (*i=1,2,3…I*); *j* is seasonal index *j*, *k* is crop type (*k=1,2,3…K*), NB_{hik} is net benefit of crop *k* in sub-area *h* for soil type *i* (US$.ha^{-1}), and $X_{hijk,}$ is irrigated area of crop *k* in sub-area *h* for soil type *i* during season *j* (ha).

This GAs model requires encoding schemes that transform the decision variables (irrigated area of crop *k* in sub-area *h* for soil type *i* during season *j*) into chromosome. Then, the genetic operations (reproduction, crossover, and mutation) are performed. This study used population size = 80, crossover probability = 0.85, mutation probability = 0.01 (Jain *et al*., 1998).

After the chromosomes (irrigated area of crop *k* in sub-area *h* for soil type *i* during season *j*) of the initial population have been determined, the gross benefit of the scenario during the season *j* is calculated by the objective function and constraints. The gross benefit of the system for each chromosome is returned to the GA to evaluate its fitness. The gross benefit of the irrigation project is defined as fitness function in this study. Next, the reproduction including selection, crossover and mutation is performed for creating a new irrigated area of crop parameters in next generation. This procedure is repeated until the criterion is satisfied as described in Figure 16.

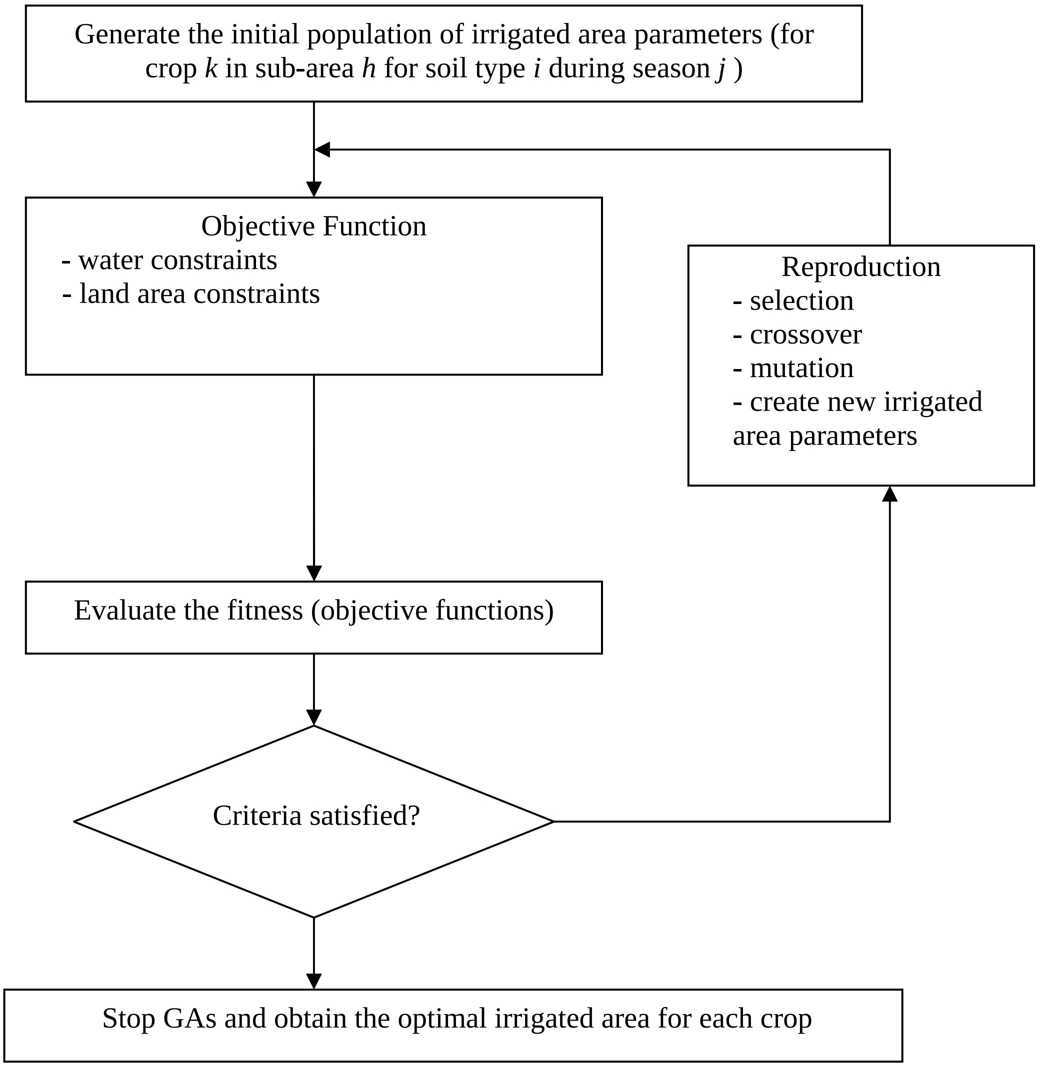


Figure 16 Integration of GAs for searching irrigated area of each crop

The constraints of the model can be divided into two categories including water constraint and land area constraint. The water constraint considered the irrigation efficiency from the mathematical model, due to the varied irrigation efficiencies were closed to the actual irrigation efficiencies all series. Therefore, the overall water efficiency of the Nam Houm irrigation scheme was used for mono-functioned character, which can describe as:

$$E_{overall} = \frac{SWR - ER}{WDF} x100 \qquad (3.25)$$

where $E_{overall}$ is overall efficiency of the irrigation project, SWR is total scheme water requirement(m^3), ER is effective rainfall (m^3), and WDF is water delivery to the paddy fields.

$$SWR = \sum_{u=1}^{U} \int_{v=1}^{V} WR_{vu} x A_{vu} \qquad (m^3) \qquad (3.26)$$

$$WDF = (I * E_c + N) - (D + C) \quad (m^3) \qquad (3.27)$$

where: I is intake water through main canal (m^3), E_c is canal efficiency, N is total natural flow entering command area (m^3), D is drain water to sink outside without reuse or non-utilizable water supply (m^3), C is committed flow to other areas (e.g legally and conventionally committed outflow from command areas to outsides (m^3)), WR_{vu} is crop water requirement ($mm.day^{-1}x10^{-3}$) of crop type u at the day v, A_{vu} is actual cultivated area (m^2) of crop type u at the day v.

For Paddy:

$$WR_p = ET_o * K_c + P + L_P \qquad (3.28)$$

For Non-paddy Crop:

$$WR_N = ET_o * K_c \qquad (3.29)$$

For Fish pond

$$WR_p = ET_o * K_c + P \qquad (3.30)$$

where ET_o is potential or reference evapo-transpiration in $mm.day^{-1}$, K_c is crop coefficient (dimensionless), P is percolation in $mm.day^{-1}$, and L_P is land preparation in $mm.day^{-1}$.

For practical water requirement for fish ponds are calculated in the same way as water requirement for crops. A fish pond is comparable with an evaporation pan therefore one K_c value should be used throughout the year. It is recommended to use a K_c value of 1.2 for calculating requirement for fish pond. The net crop water requirement is not greater than the total available water of the irrigation scheme multiplying the irrigation efficiency of irrigation project, which described as:

$$\sum_{h=1}^{H} \sum_{i=1}^{I} \sum_{k=1}^{K} \sigma_{hijk} X_{hijk} \leq E_{overall} Vd_j \qquad (3.31)$$

$$\sigma = WR_{vu} \text{ x Stage of crop development} \qquad (3.32)$$

where σ_{hijk} is crop water requirement rate of crop k in sub-area h for soil type i during season j ($mm.ha^{-1}$), Vd_j is total available water of the irrigation system during season j (Mm^3), and $E_{overall}$ is the overall irrigation efficiency of the irrigation project.

The seasonal available water of each zone (q_{hj}) is calculated by multiplying the net available water of the irrigation system with a proportion of each zone area and total area (T_j), which presented as:

$$q_{hj} = E_{overall} Vd_j \left(\frac{X_{hj}}{T_j} \right) \qquad (3.33)$$

$$\sum_{i=1}^{I} \sum_{k=1}^{k} \sigma_{hijk} X_{hijk} \le q_{hj} \qquad (3.34)$$

For the land constraint, the summation of all zone area is not greater than the available total area of scenario during season *j*; which described as:

$$\sum_{h=1}^{H} X_{hj} \le T_j \qquad (3.35)$$

In each zone divided into several sub-areas suitable to soil type. The total land area of all soil type is not larger than the available area of the zone, which presented as:

$$\sum_{i=1}^{I} \sum_{k=1}^{K} X_{hijk} \le X_{hj}; \quad \text{for } h=1,2,3....H \qquad (3.36)$$

The net irrigated area of all crops is not greater than the land area of each soil type. The irrigated area of each crop is not larger than the suitable area for its cultivation. These constraints are of the following form:

$$\sum_{k=1}^{K} X_{hijk} \le X_{hij}; \qquad (3.37)$$

for h= 1,2,3,…H and i = 1,2,3…I

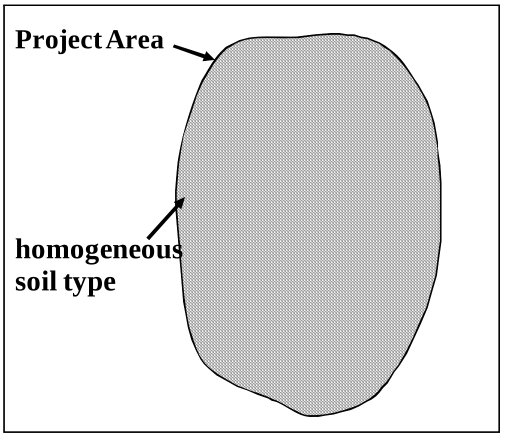
$$X_{hijk} \le S_{hijk}; \qquad (3.38)$$

for h= 1,2,3,…H and i = 1,2,3…I and k= 1,…K

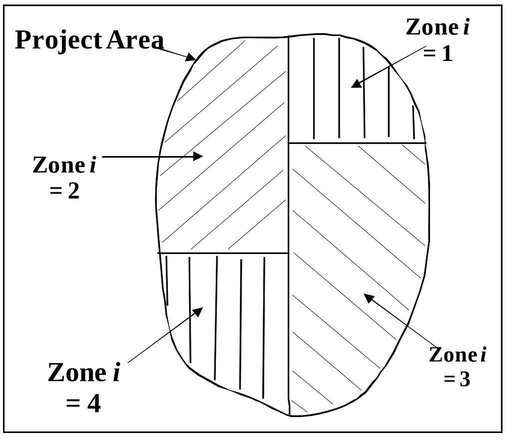
$$X_{hijk} \ge 0 \qquad (3.39)$$

where S_{hijk} is amount of suitable land for the cultivation of crop k in sub-area h for soil type i during season j .

In order to consider the multi-functioned character of paddy field of the suitable soil type for cultivation each crop, the zone area is divided into several suitable soil types (see figure 17).



General project



Proposed GA model

Figure 17 The suitable soil type for the cultivation in a zone area.

3.11 Methodology and approach

The pilot project of this study is the Nam Houm Irrigation Scheme, Laos PDR. The location and Schematic plan of the study area are shown in Figures 12. The methods are presented as the follows:

Assessment of Water Requirement

The water requirement is appraised using all parameters conducted in the fields. Those parameters are described as follows:

1. Evaporation, ETo

The ETo was recorded using A-pan instillation in the study area. The data was recorded on daily basis and the recorded results are made available in Nam Houm Irrigation Scheme Organization (NISO) for both dry and wet seasons. The ETo is not used for calculation of ETc of paddy since the ETc of paddy is directly measured in the paddy field. The ETo is used for calculation of ETc for cash crops.

2. Rainfall

Rainfall (R) was recorded by installation of simple rain gage at the same place as ETo as installed. The recorded results are provided in separated documents.

3. Crop Coefficient, Kc

The Kc is referred from the book of water requirement (MAF). The Kc of paddy in dry and wet seasons was distinguished.

4. Evapo-Transpiration, ETc and Percolation

The ETc and Percolation were directly recorded in the paddy field by installation of equipment shown in Figure 3. The water levels which include ETc and Percolation were recorded every day through the dry and wet seasons. The installation was made in 3 places at up, middle, and down-stream commanded areas. The data used for the calculation was the average of these 3 stations.

The ETc of paddy is also cross checked with data calculated from ETo (ETc = ETo x Kc). The Kc was mentioned above.

The ET of fish pond is calculated by installation of staff gauge in 2 fish ponds at up- and middle-stream command area. The water level of fish pond which consists of ET of fish pond and percolation was recorded every day. The inflows and outflows of fish pond during water level monitoring were controlled and recoded in order to obtain water level properly. The water level of fish pond data is used as water requirement for fish pond.

5. Identify actual planted area

Identification of actual irrigated areas was observed in dry and wet seasons. The GPS was used to record points and boundaries of actual irrigated areas. The head of WUGs were interviewed to mark their own actual boundary of irrigated areas. The collected information was then plotted into schematic ground plan of irrigation scheme. The actual irrigated areas were monitored every 10 days. The actual planted areas were used to calculate system water requirement.

6. Cropping pattern and crop calendar

The data collection will be done and provided to each water user group to record cropping pattern and crop calendar for their own groups. The information will be crosschecked by conducting field observation for 2 times in dry season and for 2 times in wet season. This information includes: kinds and hectares of crops to be grown; date/ time and length (number of days) of land preparing, translating and harvesting periods.

7. Water requirement for different agricultural activities

Because of various agricultural activities are practiced in the project, therefore the water requirement (WR in mm.day^{-1}) for each agricultural practice was calculated by the equations (3.28 to 3.30).

(a)

(b)

Figure 18 ETc Installation

Percolation is considered when calculating water requirements for paddy and fishpond. However, percolation is assumed to be minor and neglectible when calculating water requirement for cash crops.

Inflow and outflow measurements

To access water balance, flow measurement points were determined to scope with all inflows and out flows. Not only flows from irrigation canals were measured, all natural inflows and outflow were covered. The measured data in each canal is provided in separated documents.

The measurements in irrigation canals were conducted according to the irrigation schedule of the project or gate operation at the intake of each canal, but mostly with the average for 2 times a month. One time spends approximately for 7 days for measurement. Measurement teams were divided into 2 teams, one team conducted flow along canal system and the other team conducted flow measurement at natural steams.

The current meter is provided by MRCS to conduct flow at canals. Figure 19 shows the field work of the team conducting flow measurement at main (left) and tertiary (right) irrigation canals.

The methodology of flow quantity calculation was by following the instruction provided by Mekong River Commission Secretariat (MRCS) and Department of Irrigation (DOI) with the brief explanation as follows:

According to Figure 20, measurement was conducted along the vertical depth of 0.2, 0.6, and 0.8 in each divided segment at cross section area. In case when water level is lower than 0.6 m, only 0.2 and 0.8 of depth was measured. The average velocity was calculated in each segment, and then discharge of each segment was calculated with each cross section area (a_i) and average velocity (V_i). The total discharge at each measurement point is to sum up of discharge of each segment cross section area.

(a) (b)

(c) (d)

Figure 19 Flow Meter Equipments and Flow Conducting.

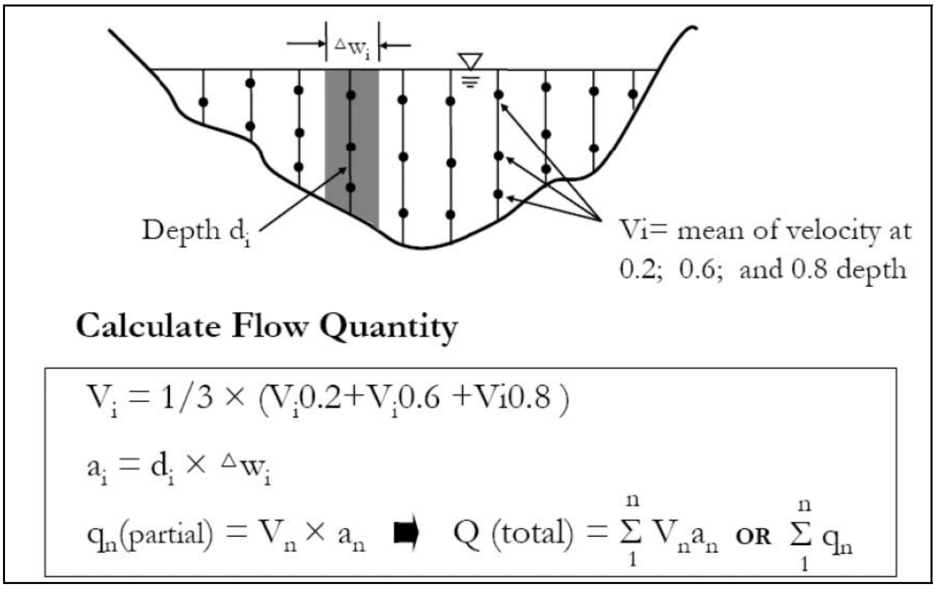


Figure 20 Calculation of Flow Quantity

3.12 Illustrative application

The 18-year (1989-2007) of seasonal flow, irrigated area, irrigation efficiency, crop water requirement, related evaporation and effective rainfall of the Nam Houm.

Irrigation Scheme during dry season (November-April) was considered for illustrative application of the proposed approach. Figure 12 presents the location of the Nam Houm Irrigation scheme in the Central of Lao PDR. The Nam Houm Irrigation System (NISO) has an estimated irrigation service area of 4,200 hectares during wet season and 2,400 hectares during the dry season.

The history record of irrigated area in Nam Houm from 1989 to 2007 is used to the application. The average irrigated area during the wet season is 1,986 hectares and 1,441.79 during the dry season (rice, non-rice crops and fish ponds). It must be noted that the reported wet season irrigation area does not represent the total area planted during the wet season as the 4,200 hectares. The most areas are planted to rice during the wet season. Most of these areas depend on rain for water supply.

The reservoir has a catchments area of 108 km^2 with annual inflow of 149.5 Mm^3. The maximum storage is 60 Mm^3 (active of 54 Mm^3, and dead of 6 Mm^3.). The estimation of maximum flood level is 190.1 MSL (mean sea level) and crest of dam of 192.2 MSL, spillway at 189.1 MSL and intake at 178.8 MSL. Reservoir was not filled-up to maximum capacity in the past wet season 2006.

For water distribution practices, water balance is considered before every cultivation season. If the storage kept as high as 189.1 MSL (in other words 60 Mm^3) at the end of rainy season, a constant amount of water will be supplied continuously with no limitation. However, a rotation method is applied when water in the reservoir is insufficient. When available water level under normal level, cultivated area are estimated according to water storage e.g., in 2003, water level of 186.41 MSL (36 Mm^3) could irrigate only 1,500 ha.

Due to the cultivated areas are limited according to available water. Water delivery is limited to one zone at the same time with regular rotation from zone 1 to zone 3. Some areas are abandoned, especially the areas which are located far away from the canals. The overall irrigation efficiency of the Nam Houm Irrigation Scheme is 70.52 % in 2006 (MRCS annual report. 2006).

Table 5 Historical data of various variables

Year	Total irrigated area last yrs	Farmer Participation	Inflow	Unit Cost Rice	Actual irrigation efficiency
	(ha)	(%)	($x10^3m^3$)	($Kip.kg^{-1}$)*	(%)
1989	473.16	20.55	7,836.52	180	79.27
1990	493.16	23.55	8,613.05	212	82.76
1991	565.20	29.72	11,398.13	230	79.19
1992	713.20	26.50	10,079.26	255	79.22
1993	635.90	22.27	8,366.85	283	79.26
1994	534.50	29.80	11,164.54	334	78.83
1995	715.26	41.60	15,701.09	633	78.37
1996	998.51	45.10	16,856.32	803	77.98
1997	1,082.35e	53.04	22,158.92	1,305	77.45
1998	1,405.35	54.33	22,604.72	1,708	77.87
1999	1,440.70	60.00	25,098.74	1,871	77.33
2000	1,581.81	91.67	38,331.21	2,000	76.77
2001	2,376.05	99.63	40,781.55	2,200	77.05
2002	2,467.05	102.38	42,098.40	2,648	78.34
2003	2,672.17	58.33	30,596.23	2,919	62.44

Table 5 (countinved)

Year	Total irrigated area last yrs	Farmer Participation	Inflow	Unit Cost Rice	Actual irrigation efficiency
	(ha)	(%)	$(x10^3 m^3)$	$(Kip.kg^{-1})$*	(%)
2004	1,575.17	100.00	46,293.38	2,897	69.85
2005	2,635.17	100.00	45,298.95	3,750	71.56
2006	2,643.96	68.75	31,642.78	4,069	70.45
2007	2,644.96	69.55	34,642.78	4,070	70.40

Note: * 1 US$= 10,000 kip (Source : MRCS. 2007)

The total area of scenario for several years cultivation is 2,400 ha (1 ha = 10,000 m^2) that is divided in to 3 zones, including zone No. 1 of 550 ha, zone No. 2 of 900 ha and zone No.3 of 950 ha. which presents on table 6.

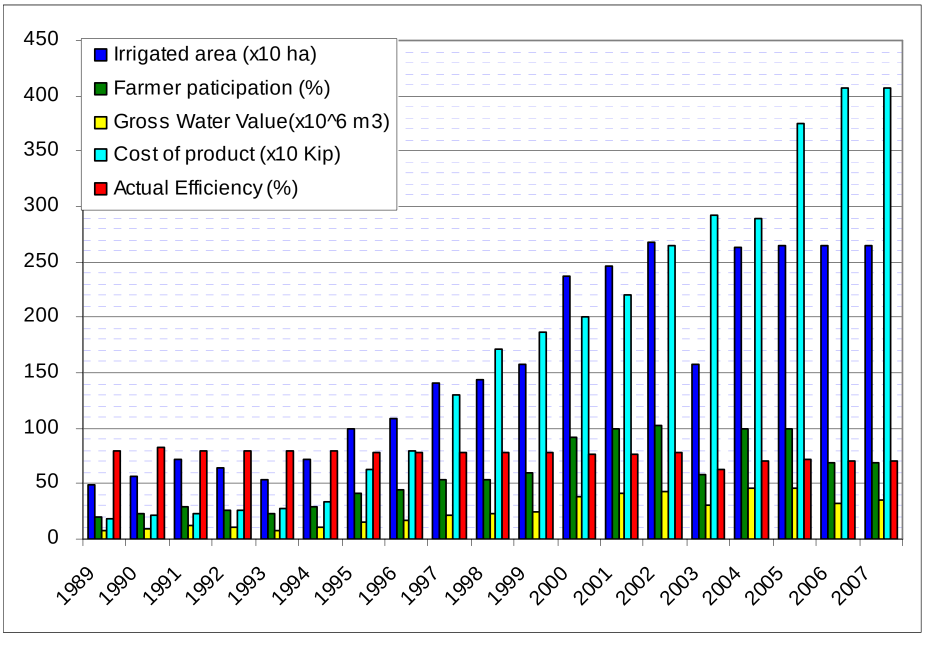


Figure 21 History data of all variables

Table 6 Irrigated area for each zone

WUA	Irrigation Blocks	Total Area of Dry season (ha)	Irrigable Area (ha)	Design. Area of Dry season (ha)	Farmers (HH)	Remarks
Zone 1 (N1)	22	720.06	612.46	550.00	636	Low ISF payment
Zone 2 (MC Right)	15	735.65	735.65	900.00	544	High ISF Payment
Zone 3 (MC Left)	21	1,013.38	899.09	950.00	522	Fair ISF Payment
Total	58	2,469.09	2,247.20	2,400.00	1,702	

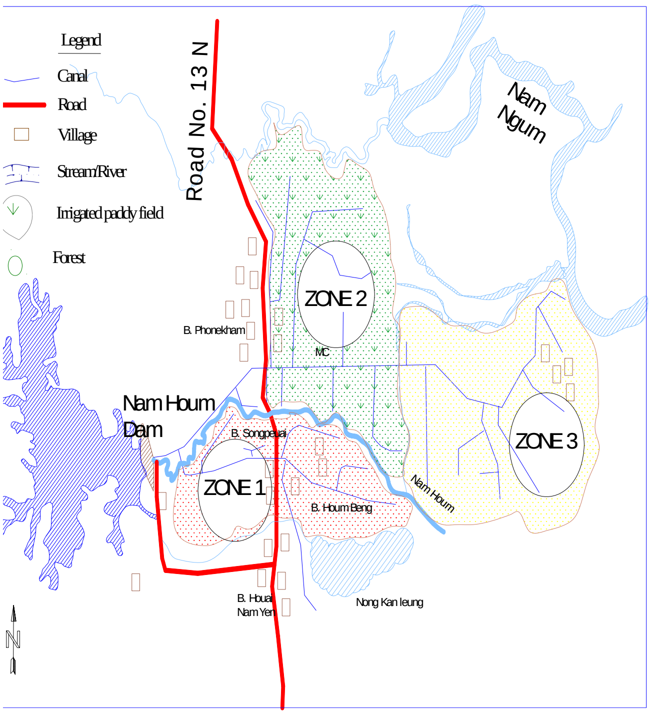


Figure 22 Nam Houm Irrigation Scheme

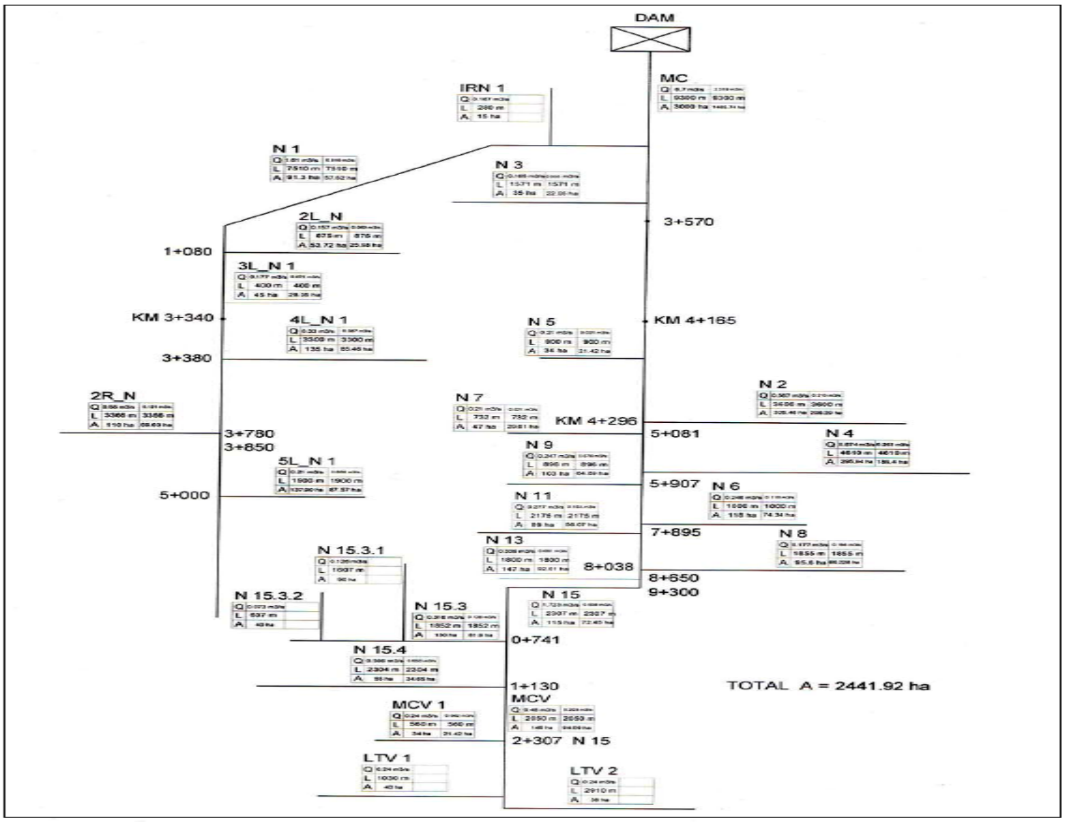


Figure 23 Schematic of Nam Houm Irrigation project

Chapter 4

Results of Analysis

This chapter presents procedure of analysis and its results of the Mathematical Model for estimating varied irrigation efficiency, Linear Programming for finding an optimal cropping pattern for irrigation planning and using Genetic Algorithm model for finding of the optimization cropping pattern in Nam Houm Irrigation Scheme, Naxaythong district, Vientiane capital, Lao PDR. The methodology of analysis consists following details:

1. Symbols use for presentation of data analysis
2. Results of analysis from the Mathematical Model
3. Results of stakeholders involved in water resources management
4. Results of analysis from the LP model
5. Results of analysis from GA model

6 Discussion

4.1 Symbols use for presentation of data analysis

A_{ji}	-	actual cultivated area (m^2) of crop type *i* at the day *j*.
C	-	committed flow to other areas (e.g legally and conventionally committed outflow from command areas to outsides (m^3)
CWR_{jk}	-	crop water requirement rate of crop *k* during season *j* ($mm.ha^{-1}$)
$\bar{e}$	-	the average of the estimated irrigation efficiency of the scenario during season *j*
$\bar{\hat{e}}$	-	the average of the actual irrigation efficiency of the scenario *j*
$\hat{e}_j$	-	the actual irrigation efficiency of the scenario *j*
e_j	-	the estimated irrigation efficiency of the scenario during season *j*
E_c	-	canal efficiency(%)
$E_{overall}$	-	the overall irrigation efficiency of the irrigation project (%)
ER	-	effective rainfall (m^3)
ET_o	-	potential or reference evapo-transpiration ($mm.day^{-1}$)
σ_{hijk}	-	crop water requirement rate of crop *k* in sub-area *h* for soil type *i* during season *j* ($mm.ha^{-1}$)
GA	-	Genetic Algorithm model
I	-	intake water volume through main canal (m^3)
K_c	-	crop coefficient (dimensionless)
Lp	-	land preparation ($mm.day^{-1}$)
LP	-	Linear Programming model
n	-	the number of annual historic data
N	-	total natural flow entering command area (m^3)
NB_{hik}	-	net benefit of crop *k* in sub-area *h* for soil type *i* ($Kip.ha^{-1}$)
P	-	percolation ($mm.day^{-1}$)
q_{hj}	-	the seasonal available water of each zone ($m^3.sec^{-1}$)
r	-	the coefficient of correlation
R^2	-	coefficient of determination (%)

S_{hijk}	-	amount of suitable land for the cultivation of crop k in sub-area h for soil type i during season j
SWR	-	total scheme water requirement (m^3)
T_j	-	total cultivated area of each zone j (m^2)
Vd_j	-	total available water of the irrigation system during season j (Mm^3)
V_{gross}	-	the gross water diverted from the source to the conveyance system (Mm^3)
V_{net}	-	the net volume of crop water requirement (Mm^3)
WDF	-	water delivery to the paddy fields (m^3)
WR_{vu}	-	crop water requirement ($mm.day^{-1}x10^{-3}$) of crop type u at the day v
X_{jk}	-	cropped area of crop k during season j (ha)
X_{hijk}	-	irrigated area of crop k in sub-area h for soil type i during season j (ha).
y_{ij}	-	estimated irrigation efficiency of scenario i during the sea
Z_j	-	the gross benefit of the scenario during the season j

4.2 Results of analysis from Mathematical Model

Table 7 shows the parameters of multiple regression functions. The results showed that the parameters of determination of multiple regressions functions provided the optimal condition for calibration the varied efficiencies.

Table 7 Parameters of multiple regression function for estimating irrigation efficiency.

Data input	Multiple coefficient	Total Area (X_1)	Farmer Participation (X_2)	Inflow (X_3)	Unit Cost Rice (X_4)
	a	b_1	b_2	b_3	b_4
X_1-X_2	4.962	-0.129	0.071		
X_1-X_3	4.720	-0.107		0.037	
X_1-X_4	4.801	-0.057			-0.010
X_2-X_3	8.696		0.768	-0.742	
X_3-X_4	4.196			0.071	-0.079
X_4-X_2	4.529		-0.093		0.115
X_1-X_2-X_3	8.733	0.033	0.774	-0.750	
X_1-X_2-X_4	4.711	-0.055	0.114		-0.063
X_1-X_3-X_4	4.351	-0.061		0.074	-0.047
X_2-X_3-X_4	8.847		0.786	-0.769	0.006
X_1-X_2-X_3-X_4	8.842	-0.003	0.783	-0.766	0.007

The mathematical model was evaluated by considering the coefficient of correlation (r) and coefficient of determination (R^2) which defined based on the actual irrigation efficiency and the estimated irrigation efficiency of all variables input as shown on table 8 . The coefficient of correlation (r) of relationship between irrigated area, participation of stakeholder in water resources management, available inflow and product cost (X_1-X_2-X_3-X_4) highest values is 0.940 of all variables input and also the coefficient of determination (R^2) of all variables is highest values of 88.3% respectively. Therefore, these variables input with X_1-X_2-X_3-X_4 is suitable for estimating irrigation efficiency given the optimal condition of calibration. The least value of coefficient of correlation (r) is 0.729 of total irrigated area and inflow relationship(X_1-X_4). and also the coefficients of determination is 52.3%.

The power regression equation of mathematical model for relationship between irrigated area, participation of stakeholder in water resources management, available inflow and product cost (X_1-X_2-X_3-X_4) is near non-linearity if the comparison between others relationships with the values of exponent of (X_i) and the coefficients of determination (R^2) which it showed in table 8, the multiple regression function as follow:

$$y = 6918.816 * X_1^{-0.003} * X_2^{0.783} * X_3^{-0.766} * X_4^{0.007} \qquad (4.1)$$

Table 8 Coefficients of correlation and determination

Variables input	Average of Actual irrigation efficiency	Average of Estimated efficiency from model	Coefficient of correlation	Coefficient of determination
	(%)	(%)	r	R^2 (%)
X_1-X_2	76.02	75.62	0.759	57.6
X_1-X_3	76.02	75.89	0.729	53.2
X_1-X_4	76.02	75.78	0.723	52.3
X_2-X_3	76.02	75.91	0.939	88.1
X_3-X_4	76.02	75.65	0.733	53.8
X_4-X_2	76.02	143.81	0.784	61.4
X_1-X_2-X_3	76.02	76.08	0.939	88.2
X_1-X_2-X_4	76.02	75.95	0.798	63.7
X_1-X_3-X_4	76.02	75.78	0.748	56.0
X_2-X_3-X_4	76.02	75.52	0.939	88.2
X_1-X_2-X_3-X_4	76.02	75.42	0.940	88.3

Figure 24 shows the relationship between actual irrigation efficiency and estimated irrigation efficiency for all variables input with the highest value of coefficient of correlation, r. The graph showed that the estimated irrigation efficiency from the model was much closed to the actual irrigation efficiency for all variables of multiple regression function, with consideration of the irrigated area, participation of stakeholder in water resources management, seasonal inflow and product cost.

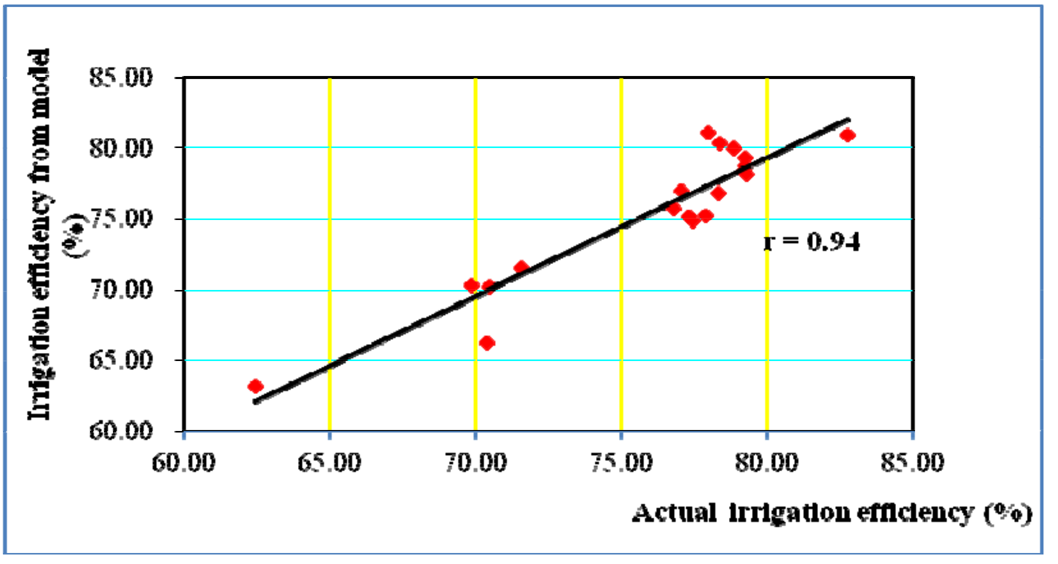


Figure 24 Actual and estimate irrigation efficiency for inputting all variables

Table 9 Deviation between the irrigation efficiency of all variables

Year	Actual irrigation efficiency (%)	Estimated irrigation efficiency (%)	Deviation
	$\hat{e}_j$	e_j	$\lvert \hat{e}_j - e_j \rvert$
1989	79.27	78.12	1.15
1990	82.76	80.94	1.82
1991	79.19	78.37	0.83
1992	79.22	78.71	0.51
1993	79.26	79.32	0.06
1994	78.83	80.02	1.19
1995	78.37	80.31	1.95
1996	77.98	81.07	3.09
1997	77.45	74.89	2.56
1998	77.87	75.24	2.63
1999	77.33	75.10	2.23
2000	76.77	75.67	1.10
2001	77.05	76.99	0.07
2002	78.34	76.84	1.49
2003	62.44	63.20	0.76
2004	69.85	70.29	0.44
2005	71.56	71.49	0.07
2006	70.45	70.21	0.24
2007	70.40	66.25	4.15

Table 9 shows the deviation between the estimated irrigation efficiency and the actual efficiency which calculated from irrigated area, participation of stakeholder, product cost and value of available inflow. The results shown that the estimated irrigation efficiencies are closed to the actual irrigation efficiencies all series. Except in 2007, the deviation is quite high with number of 4.15. It indicates that the varied irrigation efficiency by using mathematical model is more precise than the constant efficiency. Consequently, the parameters of multiple regression function with all variables input (X_1-X_2-X_3-X_4) of the illustrative model is appropriately to find the varied irrigation efficiency for irrigation planning.

4.3 Results of stakeholders involved in water resources management

Statistic data analysis

1. Evaporation (ETo)

Figure 25 shows the monthly average of ETo recorded from November 2009 to October 2010. The average ETo was estimated at 3.32 $mm.day^{-1}$ in dry season and 4.47 $mm.day^{-1}$ in wet season. The ETo is generally lower in dry season from November to June and higher in wet season from June to October. The higher humidity in wet season might be the reason of the high ETo. The peak is clearly observed in February in dry season and in August in dry season. The daily recorded value is provided in separated documents.

2 Rainfall

The Figure 25 also shows the rainfall observed at the same period. Almost no rainfall was observed in dry season of 2008 to 2009. The average rainfall in dry season was 0.07 $mm.day^{-1}$, while 21.09 $mm.day^{-1}$ in wet season. The peak time of rain occurred late in the in 2009 (in September), while it usually occurred in July or August in normal years. The total rainfall is also slightly lower than usual with 1,395.10 mm (3.2 mm in dry season), while approximately 1,700 mm which was the average from 1987-2007 was recorded by the DMH in Vientiane Capital.

3. Effective Rainfall

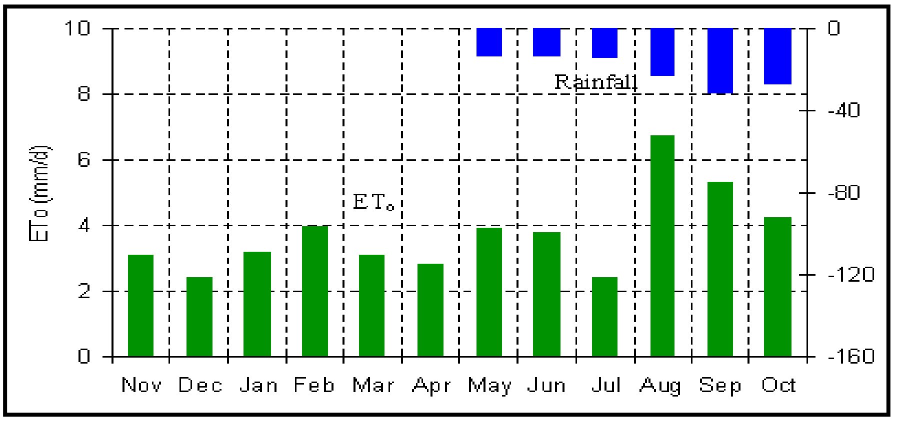


Figure 25 Evaporation and Rainfall

The total effective rainfall estimated for dry season is 0.048 MCM, but 19.79 MCM in wet season. The effective rainfall is used to calculate overall command area efficiency.

4 Evapo-transpiration (ETc)

The calculated ETc is shown in Figure 28 and 30 covering dry and wet seasons. The average of 4.03 $mm.day^{-1}$ was obtained in dry season and 6.33 $mm.day^{-1}$ in wet season. The high period of ETc occurred from February to March for the dry season and from September to October in wet season. The ETc is generally higher in wet season. The high humidity and temperature in wet season might be the reason of the high value. The ETc was recorded in 3 stations within the command areas at up-middle, and - downstream command area.

5 Deep Percolations

The Figures 26 to 28 also show the daily and average monthly percolation recorded in the same station with ETc. The percolation is higher in dry season (3.21 $mm.day^{-1}$), but only 1.19 $mm.day^{-1}$ in wet season. The reason could be the height of ground water level in wet season resulting in the low percolation in wet season. The high percolation is also observed in the command areas located near to the Nun Ngum river bank. The differences of soil types in the command areas might be the factor of different percolation rates.
The highest percolation is observed in March and April when the climate is the hottest in Laos. The percolation in wet season was gradually reduced from the beginning to the end of cultivation stages.

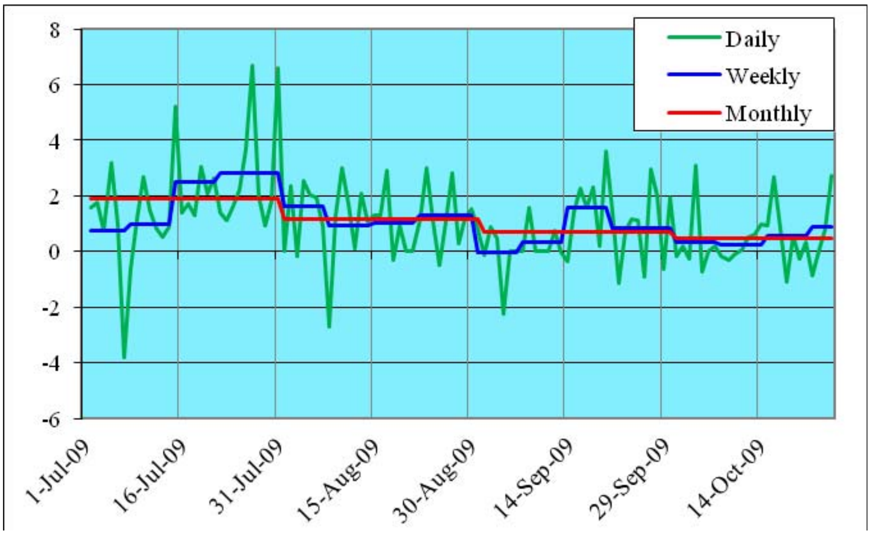


Figure 26 Calculation of Percolation in wet season

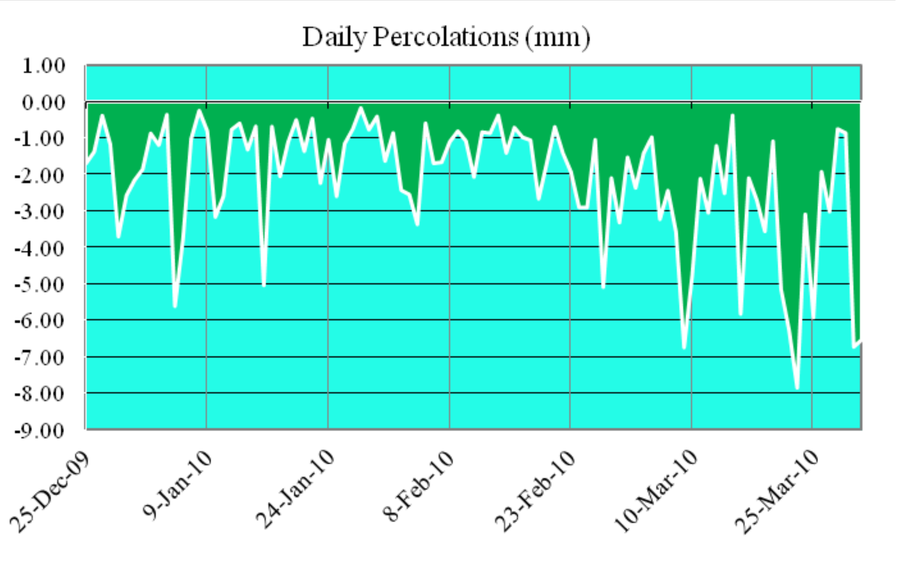


Figure 27 Calculation of Percolation in dry season

6. System Water requirement

Taking all items considered above, system water requirement is calculated and results are summarized in table 10. Total crops water requirements for dry season was estimated at 10.13 MCM (6,638.92 $m^3.ha^{-1}$ or 663.90 mm) at on-farm level. Of these total requirements, it was accounted for paddy requirement of 96. 95%, cash crops of 0.78%, and fishpond of 2.27%.

In the wet season, as much as twice of dry-season value is estimated (20.67 MCM). That is 9,133.09 $m^3.ha^{-1}$, or 913.7 mm. The higher water requirement in this season is due to longer days of rice variety, higher ETc, and larger planted area of paddy. Lesser amount is required for cash crop in wet season because of few planted areas, while demand for aquaculture is almost constant between dry and wet season.

If considering 69.07% of conveyance efficiency conducted in the project, the total water requirement at headwork or main intake is counted for 9,621.62 $m^3.ha^{-1}$ in dry season and 13,236.36 $m^3.ha^{-1}$ in wet season. These values are significantly low compared with standard value which is being used by the project of 20,000 $m^3.ha^{-1}$. So far, no detail experiment was conducted; the standard value has been borrowed from other sources, according to the project manager.

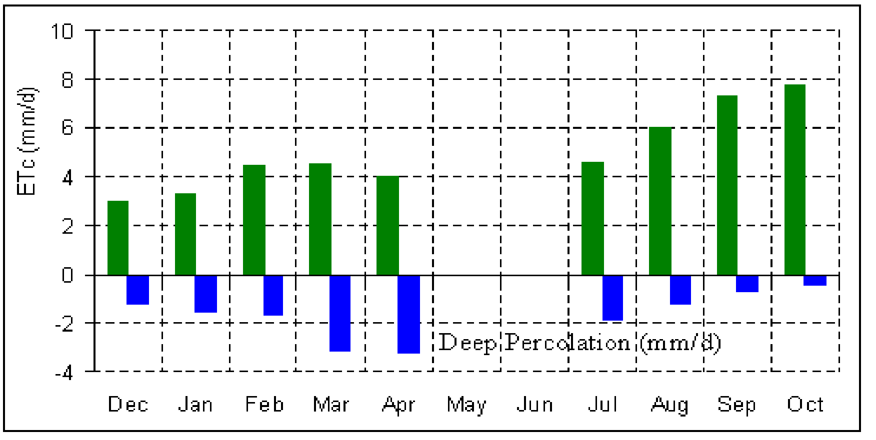


Figure 28 Evapo-transpiration and Deep Percolation.

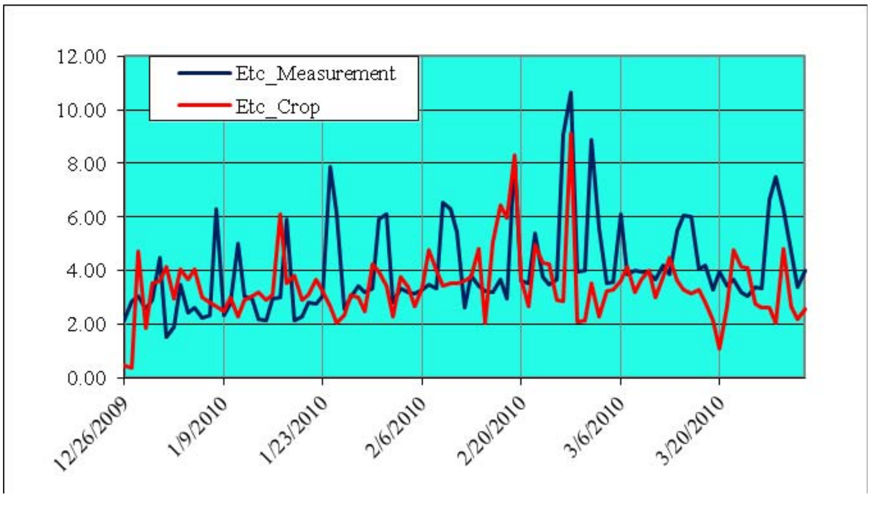


Figure 29 Calculation of evapo-transpiration in dry season

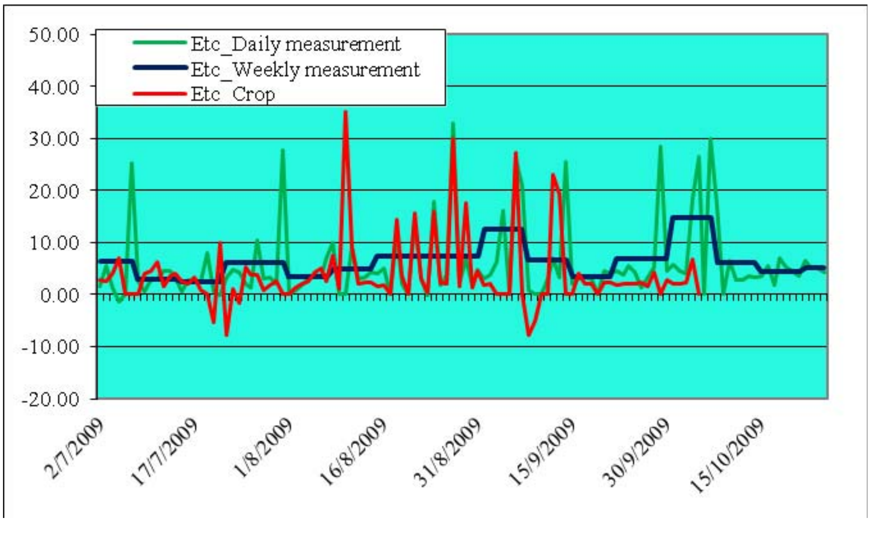


Figure 30 Calculation of evapo-transpiration in wet season

Table 10 Water Requirements at field level for each agricultural activity

Water requirement for each agricultural activity		Dry season	Wet season
Paddy (MCM)		9.817	20.370
Cash crops (MCM)		0.078	0.006
Aquaculture (MCM)		0.234	0.296
Total	MCM	10.129	20.672
	mm	663.90	913.70

7. Water Requirements and Irrigation Water Supply

The reference crop evapo-transpiration (ETo) were calculated based upon the Modified Penman method by Doorenbos and Pruitt 1977; FAO Irrigation and Drainage Paper 24 and the lasted modified Penman-Monteith method by Mr. Smith 1988.

Determination Procedure:

(1) Determine the evapo-transpiration (ETo), data from Irrigation Water Requirement of Vientiane Irrigation Plan.

(2) The second stage in estimating crop water requirements is the selection of the crop coefficient (Kc) according cropping pattern during a production season and the growth characteristics of the crop. Then ETcrop is equal to (=) Kc ETo for each period through the growing season depending on the chosen budgeting period for the application of water to supplement any rainfall.

Crop growing period and crop coefficient Kc, by Penman-Monteith method:

Land preparation and nursery stage Kc = 1.2 to 1.15; Initial/Development stage Kc = 1.0 to 1.01; Medium stage Kc = 1.05; Last stage/harvest; Kc = 1.01 to 0.84

(3) Consumptive use or Crop evapo-transpiration, Etc = ETo x Kc ($mm.day^{-1}$)

(4) Deep percolation DP ($mm.day^{-1}$) from soil percolation test = 7.87 ($mm.day^{-1}$)

(5) Determine the effective rainfall. Re ($mm.day^{-1}$)

(6) Determine Area under LP/N ,ALP/N (ha)

(7) Land preparation/Nursery , LP/N: 180mm.

(8) Land preparation/ Nursery Requirement = (3)+(4)+(6)-(5) ($mm.day^{-1}$)

(9) Net Water Duty for LP/N = (8)*0.1157 ($l.sec^{-1}.ha^{-1}$)

(10) Water Requirement for LP/N) = (9)*(6) ($l.sec^{-1}$)

(11) Determine Area under Crop Water Requirement, ACWR (ha)

(12) Crop Water Requirement, CWR = (3)+(4)-(5) ($mm.day^{-1}$)

(13) Water Duty for CWR = (12)*0.1157 ($l.sec^{-1}.ha^{-1}$)

(14) Water Requirement for CWR = (13)*(11) ($l.sec^{-1}$)

(15) Net Duty of Water = (10)+(14)

(16) Gross Duty of Water at 70 % Efficiency = [(15)*100]/70 ($l.sec^{-1}$)

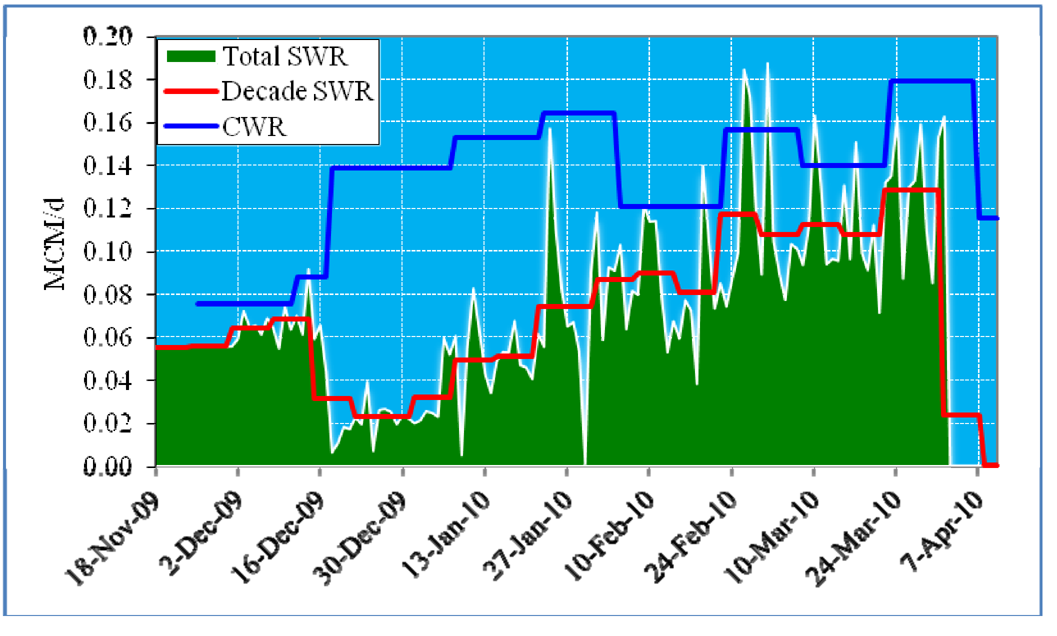
(17) Gross Duty of Water per hectare = (16)/Irrigated Area ($l.sec^{-1}.ha^{-1}$)

Figures 31 and 32 show the daily and weekly water requirement against irrigation water supply for dry and wet seasons. The water supply is calculated at the on-farm level based on the actual flow data at the main intake multiplied by conveyance efficiency (69.07%) conducted in the project.

In the dry season (Figure 31), high water requirement is observed at the land preparation and transplanting period from November to mid December. The peak water requirement is obtained at the end of February to End of March, while the lowest value appeared in development stage from mid December to beginning of January. As compared to irrigation water supply, there is a big gap between required and supplied amount. The water supply is generally higher than supplied amount, particularly from mid December to Beginning of February. The low required by crops is observed, but high supply was made in this period.

The highest supplied period is in March when paddy crop is in flowing stage and the hot climate starting.

In the wet season (Figure 32), the estimated water requirement is largely fluctuated. The heavy rainfall affects the observed value and it is difficult for estimation. The high water requirement is clearly observed, mainly from beginning of September and beginning of October. The irrigation was not supplied for the whole wet season, but as supplementary for land preparation and transplanting stage from May to July. For the rest stages, the supply water is filled by natural inflows, but mainly rainfall.



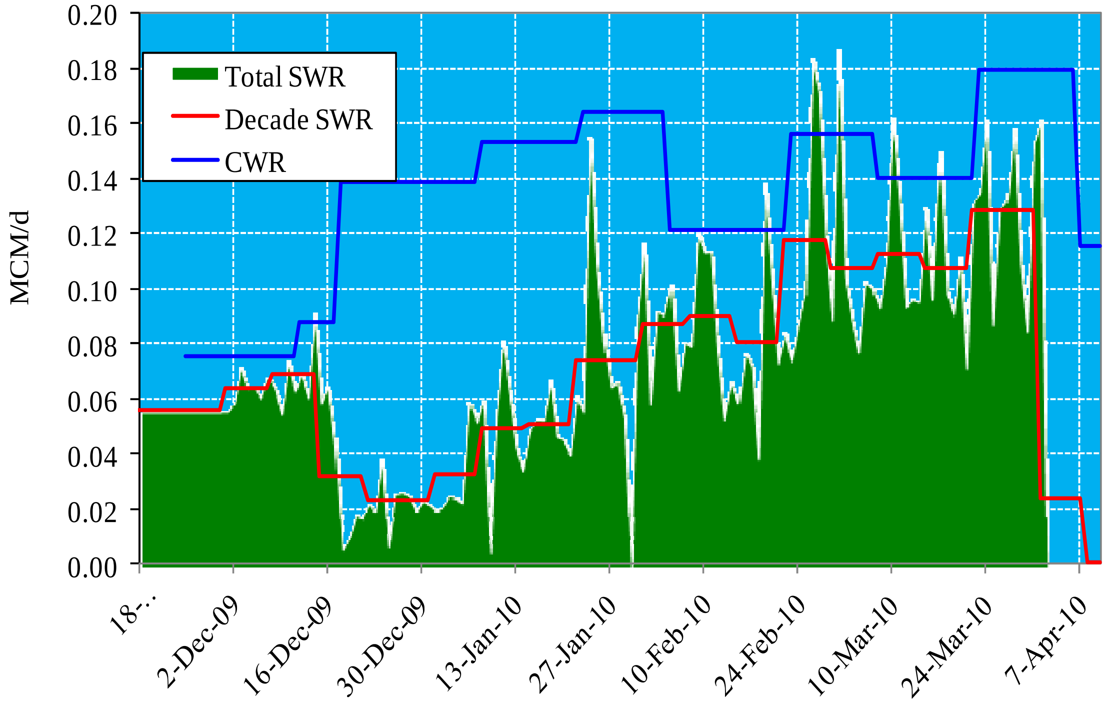


Figure 31 Water Requirements and Water Supply at Field Level (Dry Season)

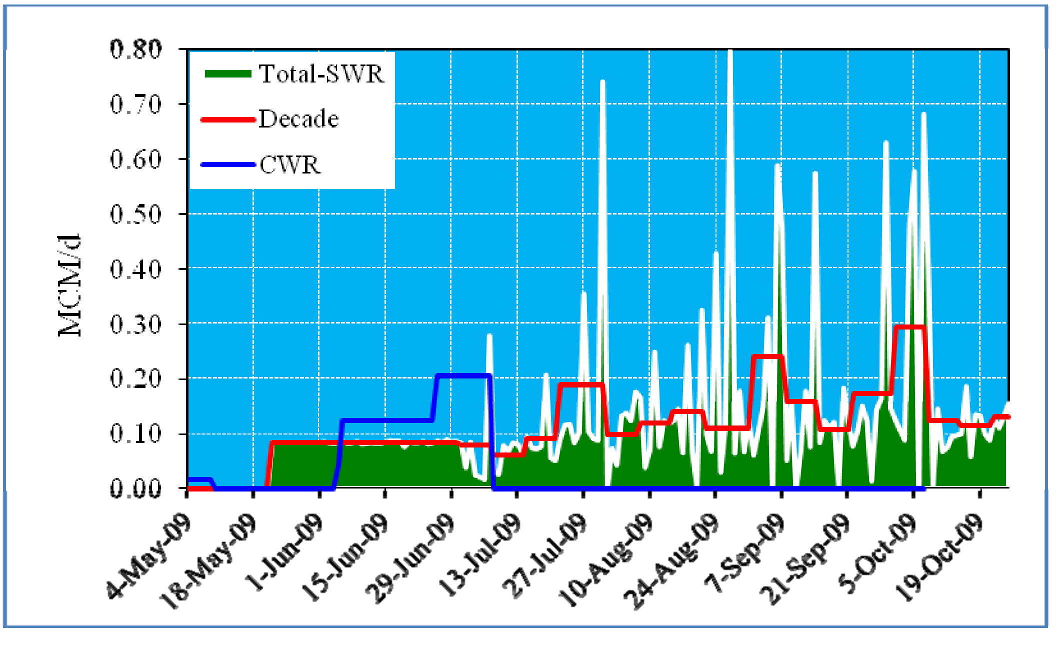


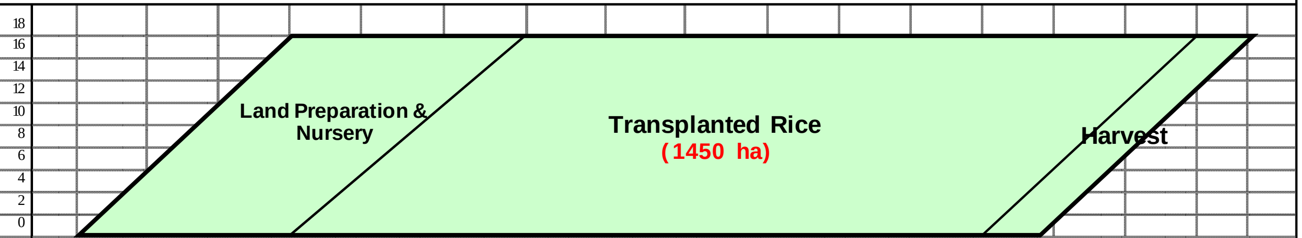
Figure 32 Water Requirement and Water Supply at Field Level (Wet Season)

Project Name: Nam Houm Irriagtion Project, Naxaythong district, Vientiane Capital.

Nursery/ Land Preparation start: 15 November.

For Irrigated Area Dry Crop (NASENG) **2400** ha *For Dry Crop Year ....*

	Particulars	Unit	Nov			Dec			Jan			Feb			Mar			Apr		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
		Dec	10	10	10	10	10	11	10	10	11	10	10	8	10	10	11	10	10	11
(1).	Potential Evapo-Transpiration, Eto	mm/d		4.30	4.10	4.00	3.99	3.67	3.75	3.95	4.05	4.08	4.52	4.95	5.01	4.85	4.75	4.71		
(2).	Crop Coefficient, Kc (Rice)			1.20	1.15	1.05	1.00	1.00	1.01	1.03	1.04	1.05	1.05	1.05	1.05	1.01	0.92	0.84		
(3).	Consumptive Use, Etc (Rice)=(1)*(2)	mm/d		5.16	4.72	4.20	3.99	3.67	3.79	4.07	4.21	4.28	4.75	5.20	5.26	4.90	4.37	3.96		
(4).	Land Preparation/Nursery, (=180 mm)	mm/d		6.00	6.00	6.00	6.00	6.00	6.00											
(5).	Percolation, P (Rice) 3.2	mm/d		3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20		
(6).	Effective Rainfall, Re	mm/d		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.21	0.41	0.69	0.99	0.11	1.13		
(7).	**Area under LP/N (Rice)**	has		**400**	**1200**	**2000**	**2000**	**1200**	**400**											
(8).	LP/N Requirement, = (3)+(4)+(5)-(6)	mm/d		14.36	13.92	13.40	13.19	12.87	12.99											
(9).	Water Duty for Lp/N, = (8)*0.1157	l/sec/ha		1.66	1.61	1.55	1.53	1.49	1.50											
(10).	**Q Requirement for LP/N, (7)*(9)**	l/sec		664.8	1932.6	3101.9	3053.2	1787.5	601.3											
(11).	**Area under CWR (Rice)**	has					**400**	**1200**	**2000**	**2400**	**2400**	**2400**	**2400**	**2400**	**2400**	**2000**	**1200**	**400**		
(12).	Crop Water Req't, = (3)+(5)-(6)	mm/d					7.19	6.87	6.99	7.27	7.41	6.48	7.74	7.99	7.77	7.11	7.46	6.03		
(13).	Water Duty for CWR, = (12)*0.1157	l/sec/ha					0.83	0.80	0.81	0.84	0.86	0.75	0.90	0.92	0.90	0.82	0.86	0.70		
(14).	**Q Requirement for CWR, = (11)*(13)**	l/sec					332.87	954.17	1617.48	2019.0	2058.9	1801.1	2148.9	2218.8	2158.5	1645.5	1036.1	279.0		
(15).	**Net Duty of Water, =(10)+(14)**	l/sec		664.8	1932.6	3101.9	3386.1	2741.7	2218.8	2019.0	2058.9	1801.1	2148.9	2218.8	2158.5	1645.5	1036.1	279.0		
(16).	Gross Duty of Water at 60% Efficiency 70	l/sec		949.7	2760.9	4431.2	4837.3	3916.7	3169.6	2884.3	2941.3	2573.0	3069.8	3169.6	3083.5	2350.7	1480.2	398.6		
(17).	**Gross Duty of Water per hectare(16)/area**	l/sec/ha		0.40	1.15	1.85	2.02	1.63	1.32	1.20	1.23	1.07	1.28	1.32	1.28	0.98	0.62	0.17		



			Nov			Dec			Jan			Feb			Mar			Apr		
(22).	Precipitation (mm)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 33 Water requirements in dry season

Project Name: Nam Houm Irriagtion Project, Naxaythong district, Vientiane Capital.

Nursery/ Land Preparation start: 10 June.

For Irrigated Area Wet Crop (NA PEE) **3000** ha *For Wet Crop Year ....*

	Particulars	Unit	Jun			Jul			Aug			Sep			Oct			Nov		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
			10	10	10	10	10	11	10	10	11	10	10	10	10	10	11	10	10	10
(1).	Potential Evapo-Transpiration, Eto	mm/d		4.00	4.11	4.12	4.13	4.14	4.15	4.15	4.15	4.15	4.16	4.17	4.25	4.72	4.52	4.50		
(2).	Crop Coefficient, Kc (Rice)			1.20	1.15	1.05	1.00	1.00	1.01	1.03	1.04	1.05	1.05	1.05	1.05	1.01	0.92	0.84		
(3).	Consumptive Use, Etc (Rice)=(1)*(2)	mm/d		4.80	4.73	4.33	4.13	4.14	4.19	4.27	4.32	4.36	4.37	4.38	4.46	4.77	4.16	3.78		
(4).	Land Preparation/Nursery, (=180 mm)	mm/d		6.00	6.00	6.00	6.00	6.00	6.00											
(5).	Percolation, P (Rice) 1.7	mm/d		1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65		
(6).	Effective Rainfall, Re	mm/d		11.71	12.31	12.53	12.73	12.93	13.30	13.50	13.20	11.61	8.61	5.61	1.41	0.91	0.41	0.00		
(7).	**Area under LP/N (Rice)**	has		**500**	**1500**	**2500**	**2500**	**1500**	**500**											
(8).	LP/N Requirement, = (3)+(4)+(5)-(6)	mm/d		0.74	0.07	-0.55	-0.95	-1.14	-1.46											
(9).	Water Duty for Lp/N, = (8)*0.1157	l/sec/ha		0.09	0.01	-0.06	-0.11	-0.13	-0.17											
(10).	**Q Requirement for LP/N, (7)*(9)**	l/sec		42.82	11.55	-160.30	-274.88	-197.92	-84.40											
(11).	**Area under CWR (Rice)**	has					**500**	**1500**	**2500**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**2500**	**1500**	**500**		
(12).	Crop Water Req't, = (3)+(5)-(6)	mm/d					-6.95	-7.14	-7.46	-7.58	-7.23	-5.60	-2.59	0.42	4.70	5.51	5.40	5.43		
(13).	Water Duty for CWR, = (12)*0.1157	l/sec/ha					-0.80	-0.83	-0.86	-0.88	-0.84	-0.65	-0.30	0.05	0.54	0.64	0.62	0.63		
(14).	**Q Requirement for CWR, = (11)*(13)**	l/sec					-402.2	-1239.6	-2158.1	-2630.4	-2511.8	-1945.3	-900.0	145.3	1632.8	1593.5	937.2	314.24		
(15).	**Net Duty of Water, =(10)+(14)**	l/sec		42.82	11.55	-160.3	-677.1	-1437.5	-2242.5	-2630.4	-2511.8	-1945.3	-900.0	145.3	1632.8	1593.5	937.2	314.24		
(16).	Gross Duty of Water at 60% Efficiency 70	l/sec		71.37	19.24	-267.2	-1128.5	-2395.8	-3737.6	-4384.0	-4186.3	-3242.2	-1500.0	242.2	2721.4	2655.9	1562.0	523.73		
(17).	**Gross Duty of Water per hectare(16)/area**	l/sec/ha		0.02	0.01	-0.09	-0.38	-0.80	-1.25	-1.46	-1.40	-1.08	-0.50	0.08	0.91	0.89	0.52	0.17		

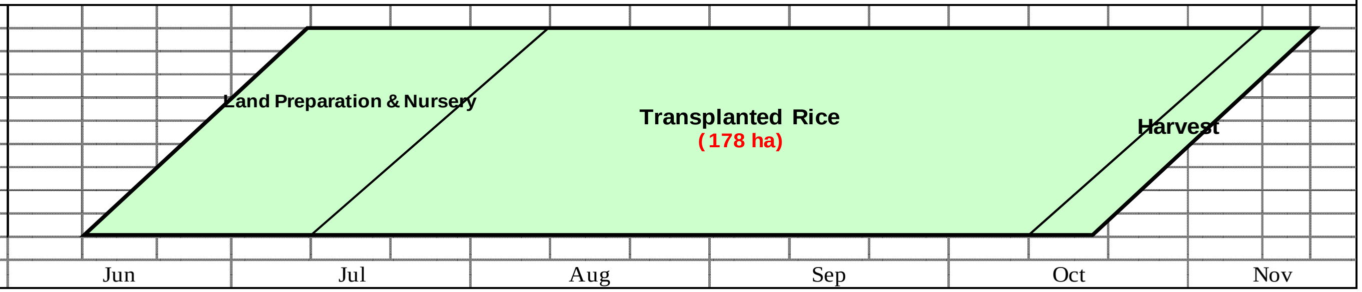


Figure 34 Water requirements in wet season

Project water management appraisal

Stakeholders involved in water management in the project

The Num Houm Irrigation Project is jointly managed by government and farmers. Therefore, stakeholders involved in water management in the project consist of the MAF level down to farmer organizations. The management appraisal of the project is described as follows:

(1) Organization chart

The project is operated by Num Houm project office belonged to the PAFSOs of Vientiane capital under the Ministry of Agriculture and Forestry. As shown in organization chart in figure 35, there are 4 main units under Num Houm project office namely agriculture and extension unit, irrigation unit, livestock unit and forestry unit. Irrigation unit is fully responsible for irrigation water management through 3 Water User Associations (WUAs). There are 11 water user groups (WUGs) in total working under WUAs, of these permanent members are 960 persons and temporary members are 380 persons. The agriculture service unit supports mainly for agricultural extension work such as training on agriculture production, technical on fertilizer application, pest and disease protection, etc.

(2) Responsibility of stakeholders

At office level, project is being managed by 6 officials in irrigation unit including Head, Deputy Head, 3 irrigation engineers, and 1 agriculture extension staff. The Head and the Deputy Head oversees the overall management and supervision of Operations and Maintenance (O&M) work. Each irrigation engineer is assigned to supervise O & M work for each Water User Association (WUA). The responsibilities of level include: O&M of the dam and reservoir, O&M of main canal. Arrangement of budget proposal for major repairs of all irrigation facilities and structures within the scheme, this proposal is submitted from the District level to Provincial level and then to Central Government.

Overall planning and supervision of the water allocation include planning, implementation, monitoring and evaluation, and Coordination with the district and provincial government for emergency repair needs of the scheme.

At farmer level, the O&M work is under responsibility of WUGs (55 WUGs as total).The responsibilities cover the O&M work from intake of secondary canal. The steering committee is formed with 1 project official (WUA), WUG head (farmer), and chiefs of the villages that command area belong to. The steering committee performs the functions of planning, problem-solving, decision-making, supervision, and technical assistance.

The organizational set-up of the WUGs consists of a leader, two deputies, and one accountant. The main task of this level is the responsibilities for water distribution, routine maintenance, and assisting unit group to collect Irrigation Service Fees (ISF). The detailed responsibilities of WUGs are listed below. Coordination and under supervision of WUAs for irrigation schedule is done by planning, monitoring water distribution, maintenance of major repairs of irrigation facilities and structures within the boundary-command areas from secondary canals to farm level, collection of ISF and remittance of ISF. Collected from farmers to the project, and monitoring progress-planted area under boundary of WUG to estimate ISF collection.

The O&M work lower than above level is unit group which consists of one head and one deputy. The group has responsibilities of O&M work at on-farm level from intake of tertiary canal.

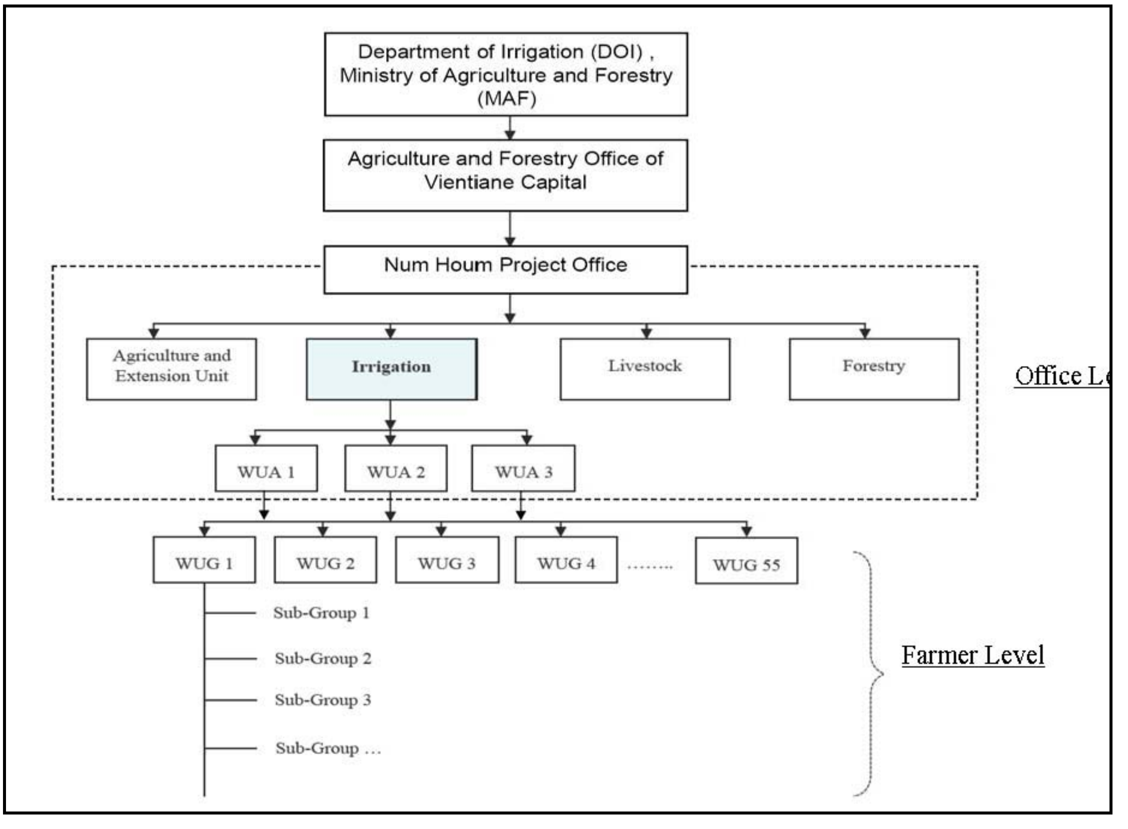


Figure 35 Organization Chart of Num Houm Irrigation Project.

(3) Level of water management

The water management and service are conducted as following procedures. The reservoir and the main canal operation is responsibility of the WUAs under the project office. The WUGs are responsible for operating of the secondary canal level coordinating with the project office and their unit groups. The unit groups cover activities at the tertiary and on-farm level. The beneficiary household is summarized in Table 11.

Water allocation plan and practice

Water allocation plan is made for dry- season cultivation, but not for wet season cultivation. However, the plan is fixed with few changes or not much fallibility adapted to the piratical situation of water allocation and actual water requirement in each cultivation stage. Active monitoring of water allocation was also not found in the project.

Table 11 Beneficiary Households.

Groups	Beneficiaries		
	No.of Village	Total Households	Beneficiary persons
WUA1 (N1)	7	441	4,970
WUA2 (RMC)	6	501	7,559
WUA3 (LMC)	6	644	7,821
Total	19	1,586	20,350

Based on observation on water allocation practice, the reservoir is operated mainly for dry season cultivation, but rarely operated during the wet season cultivation, except land preparation and transplanting and dry spell of the rain. The simple rotation method is applied at the main canal level by diving command areas into 2 parts zones as shown in table 12: (1) left side of the main canal that delivering the areas of N1, 2LN1, 3LN1, 4LN1, 2RN1, 5LN1 with total areas of 335.24 ha in dry season 2009 to 2010. the supply schedule is from Monday to Thursday, and (2) right side of main canal that delivering the areas under N3, N5, N7, N9, N11, N13, N15, N15.3, N15.4, MCV1, N2, N4, N6, N8 and MCV with total of 1,125.42 ha. The water delivery is from Friday to Sunday.

Project constraints and Problems

According to the project, the constraints can be summarized as follows:

(1) Limited budget due to poor ISF collection and limited funds from the provincial or central government,

(2) Limited experience and capability of staff,

(3) Poor condition of irrigation infrastructures,

(4) Insufficient vehicles to facilitate O&M work,

(5) Weakness in WUG functioning, especially that WUG3 is not functioned as planned,

(6) Some WUG's boundary command area is too large that is 550 ha with more than 600 beneficiaries, making it difficult to manage.

The results of the Focal Group Discussions and interviews show that the main problems in the area are:

(1) Low production due to poor soils; poor seed quality; pest and diseases infestation; insufficient water supply and high cost of production. Suggestion to improve the situation includes provision or introduction of improved farming technology through training and extension and improved water management

(2) Weak WUA – weak cooperation of members; weak implementation of the WUG Roles, Rules and regulations, poor transparency of financial transactions (financial reports not religiously prepared and not informed to members); poor monitoring and recording of irrigated areas and ISF payments. Recommended solutions include strengthening of WUGs through intensive

education and involvement of membership, improving financial transparency and strict implementation of RRR.

Table 12 Canal system.

No.	Name of Canal	Length (m)	Designed	
			Area (ha)	Discharge (m^3/s)
1	IRN1	280.00	15.00	0.167
2	N1	7,510.00	91.30	1.610
3	2L-N	875.00	53.72	0.157
4	3L-N1	400.00	45.00	0.177
5	4L-N1	3,300.00	135.00	0.330
6	2R-N	3,366.00	110.00	0.550
7	5L-N1	1,900.00	137.90	0.210
8	MC	9,300.00	428.08	6.700
9	N2	3,600.00	325.46	0.567
10	N3	1,571.00	35.00	0.165
11	N4	4,610.00	295.94	0.874
12	N5	900.00	34.00	0.210
13	N6	1,000.00	118.00	0.246
14	N7	732.00	47.00	0.210
15	N8	1,855.00	95.60	0.177
16	N9	896.00	103.00	0.247
17	N11	2,175.00	89.00	0.277
18	N13	1,800.00	147.00	0.339
19	N15	2,307.00	115.00	1.723
20	N15-3	1,852.00	130.00	0.316
21	N15-3-1	1,607.00	90.00	0.126
22	N15-3-2	637.00	40.00	0.073
23	N15-4	2,304.00	55.00	0.386
24	MCV	2,050.00	149.00	0.480
25	MCV1	560.00	34.00	0.240
26	LTV1	1,030.00	43.00	0.240
27	LTV2	2,910.00	38.00	0.240
Total		61,327.00	3,000.00	17.037

(3) Poor condition of irrigation facilities and structures due to limited funds for repair, poor maintenance, cases of vandalism (destroyed gates, animals going in and out of canals), and lack of distribution ditches for some farms. To resolve this, repair of irrigation canals and structures is necessary; and there should be strict implementation of RRR and increase of repair funds through better ISF collection.

(4) Decreasing water supply – due to degradation of watershed. To handle this situation the watershed must be protected and improved.

SWOT analysis for water resources management in the project

The SWOT analysis technique is to summarize the stakeholder involved in water resources management. The criterion for evaluation is based on the framework concept of integrated water resource management. The perspective is the sustainable development of the water of the Nam Houm Irrigation Scheme for the benefit of all.

Table 13 SWOT analysis for water resources management

INTERNAL	
Strengths	**Weaknesses**
- Availability of inflow - Acceptable project management organization - Reasonable level of water management - Water distribution is gravity system - There are large numbers of benefited households - Limited industrial activities - Reservoir is good aquaculture practices - The steering committee performs the functions of planning, problem-solving, decision-making, supervision, and technical assistance.	- Peak demand during the dry season when water is least available - Insufficient level of awareness and knowledge of best management practice in agriculture among WUGs - Lack of monitoring in water consumption - Insufficient coordination with water authorities and upstream users - Limited budget due to poor ISF collection and limited funds from the provincial or central government - Limited experience and capability of staff - Poor condition of irrigation infrastructures - Insufficient vehicles to facilitate O&M work - Weak implementation of the WUG Roles, Rules and regulations, poor transparency of financial transactions - Poor monitoring and recording of irrigated areas and ISF payments. - Low production due to poor soils; poor seed quality; pest and diseases infestation; insufficient water supply and high cost of production. - The coverage of WUAs - area coverage are too big 550 hectares to 950 hectares and the number of farmers is too large, more than 600 farmers per WUA.

Table 13 (countinved)

EXTERNAL	
Opportunities	Threats
- Provision of improved farming technology through training and extension and improved water resources management - Potential be re-studied the organization of the WUGs, the main task of this level is responsible for water distribution schedule, routine maintenance, and assisting unit group to collect Irrigation Service Fees (ISF) - Provision of overall planning and supervision of the water allocation planning, implementation, monitoring and evaluation, and coordination with the district and provincial government for emergency repair needs of the scheme. - The system provide monitoring and recording of data and information that can be made available on time for irrigation system management decisions	- Strengthening of WUGs through intensive education and to involve memberships - Improving financial transparency, to implement roles, rules and regulations (RRR) strictly - The poor condition of irrigation facilities were resolved by repairing irrigation canals and structures, strict implementation of the RRR and increase of repair funds through better Irrigation Service Fees (ISF) collection - The WUGs perform the functions of the monitoring and recording of irrigated area and ISF payments. - Under supervision of WUAs improving irrigation schedule, planning, monitoring water distribution, maintenance of major repairs of irrigation facilities and structures within the boundary-command areas from secondary canals to farm level, collection of ISF and remittance of ISF collected from farmers to the project, and monitoring progress-planted area under boundary of WUG to estimate ISF collection. - The irrigation block organizations must be strengthened to promote better cooperation and mobilization of farmers. - A procedure of planning and implementing repair and rehabilitation works through the participation of WUGs must be formulated for nationwide application.

4.4 Results of analysis from the LP model

Figure 36 shows the optimum crop pattern of the proposed and existing LP models (Mono-functioned character) for the available water of 10, 20, 30, 40, and 54 Mm^3 respectively. The crop patterns of the proposed LP model are appropriately for the targeted irrigation areas of the project for all provide water. For crop patterns of existing LP model are unsuitable for the targeted irrigation areas, because obtained patterns are larger and used more water than the proposed LP model.

Table 14 shows the gross benefit of the scenario using the proposed LP model with multi-functioned and mono-functioned characters of project. The results show that the model with multi-functioned character of project provided gross benefit higher than the model with mono-functioned characters of project for all cases. In addition the obtained patterns of considering multi-functioned are corresponding to the available land areas of the suitable soil type, while the obtained patterns of mono-functioned consideration that having only rice and cucumber area are not suitable for the availability of land areas.

Table 14 Gross benefit using LP model with multi-functioned and mono-functioned characters

Irrigated Area (ha)	Available Water (Mm^3)									
	10		20		30		40		50	
	Multi	Mono	Multi	Mono	Multi	Mono	Multi	Mono	Multi	Mono
Rice	477.2	550.0	1,017.9	650.0	1,574.7	1,400.0	2,115.3	1,600.0	2,349.0	1,600.0
Cucumber	82.1	25.0	82.1	100.0	57.9	140.0	57.9	140.0	0.0	140.0
Maize	72.7	0.0	72.7	140.0	65.6	138.0	65.6	138.0	0.0	138
Fish pond	51.0	20.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0
Net Benefit (Million Kip)	181.8	209.6	349.9	243.4	514.8	345.3	683.0	453.5	730.4	453.5

Note: Multi = Multi-functioned character, Mono = Mono-functioned character.

Figure 36 (a, b, c, d, e) shows the optimal crop pattern of the develop LP models for the available water of 10, 20, 30, 40 and 50 Mm^3 (1 Mm^3 = 10^6 m^3). The crop patterns of the LP model are approximately the targeted irrigation area of the project when having high available water.

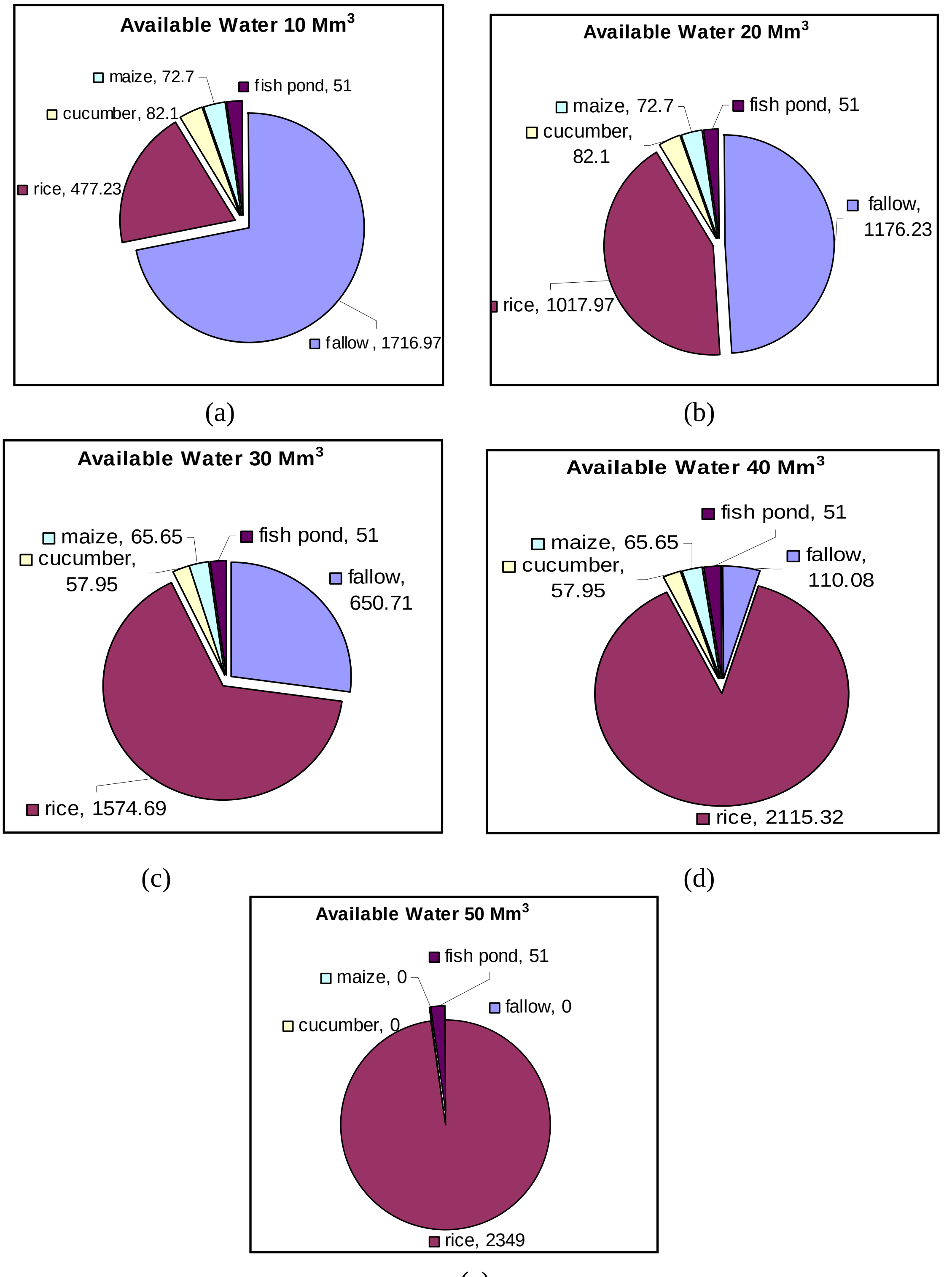


Figure 36 Optimal crop pattern of the LP model in various available water volume

Table 15 and Figure 37 show the gross benefit of the scenario using the developed LP-based model (multi-functioned character) and the mono-functioned character. The varied irrigation efficiency of 0.4, 0.5, 0.6, 0.7 and 0.8, and available release water from reservoir of 10 Mm^3 (1 Mm^3 = 10^6 m^3), 20 Mm^3, 30 Mm^3, 40 Mm^3 and 50 Mm^3 were used to test the efficiency of the proposed model. The results show that the proposed model with varied irrigation efficiency (V-Multi) provides higher net benefit than the model of constant irrigation efficiency (C-Multi) for all cases. In addition, the increasing of release water to project gives the higher net benefit following. It indicates that the variation of Multi-functioned character has a large impact on the optimal solution. For this reason, LP model with multi-functioned character of land area is appropriate for finding optimum crop pattern.

Table 15 Gross benefit of crop pattern using the developed LP model

Irrigation Efficiency	Available water (Mm^3)	Benefit (1,000 US$)	
		V-Multi	C-Multi
0.4	10	109.72	105.6
	20	205.82	178.6
	30	301.92	259.5
	40	398.02	348.5
	50	490.86	423.5
0.5	10	133.75	105.6
	20	253.72	202.8
	30	373.99	315.2
	40	490.86	443.5
	50	610.96	453.5
0.6	10	157.77	105.6
	20	301.92	202.8
	30	439.24	315.2
	40	586.94	443.5
	50	700.22	453.5
0.7	10	181.79	105.6
	20.11	349.97	202.8
	30	514.88	315.2
	40	673.02	443.5
	50	750.38	453.5
0.8	10	205.82	105.6
	20	398.02	202.8
	30	586.94	315.2
	40	730.38	443.5
	50	780.38	453.5

Note: V-Multi = vary irrigation efficiency, C-Multi = constant irrigation efficiency.

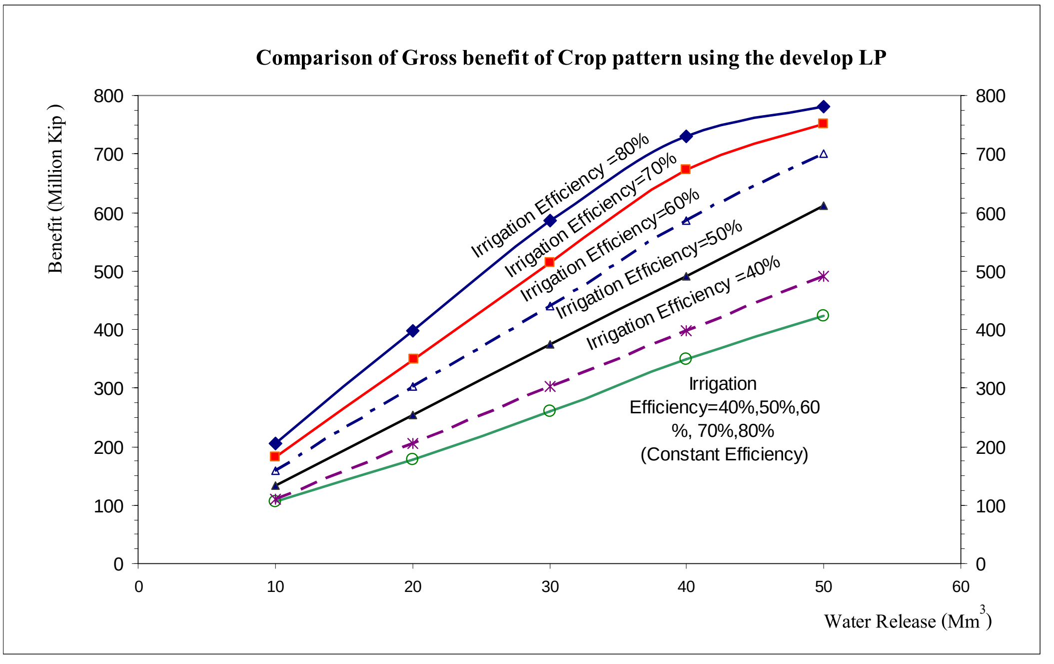


Figure 37 Comparison of gross benefit of crop pattern using the developed LP

4.5 Results of analysis from the GA model

This GA model used all history data of Nam Houm irrigation scheme, which presented in Mathematical Model. The varied irrigation efficiency of 0.4, 0.5, 0.6, 0.7 and 0.8 were used to test the efficiency of the proposed model. The evapotranspiration and percolation are present in figure 38 Irrigation water requirement and crops water requirement rate of each crop for seasonal cultivation are shown in figure 33 to 34 and table 16 respectively.

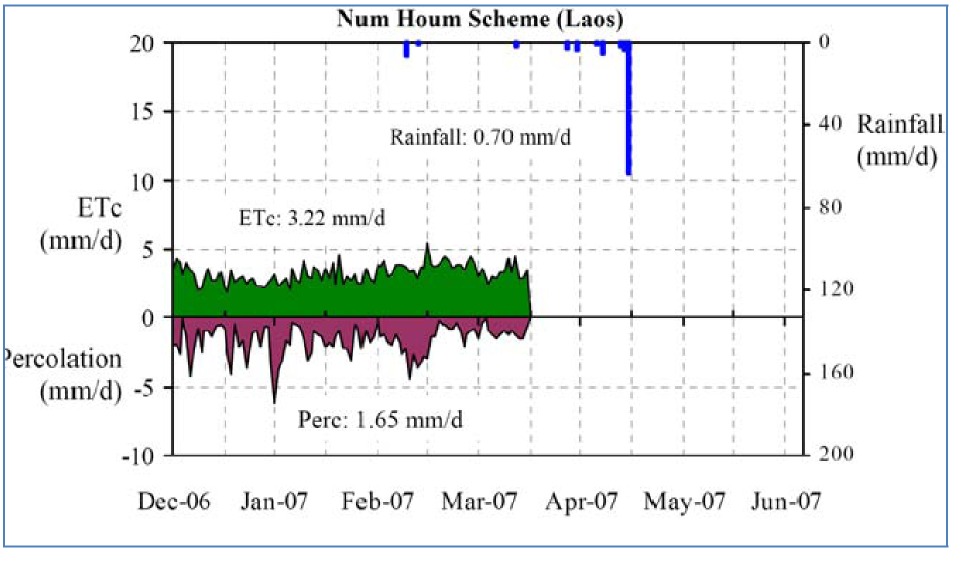


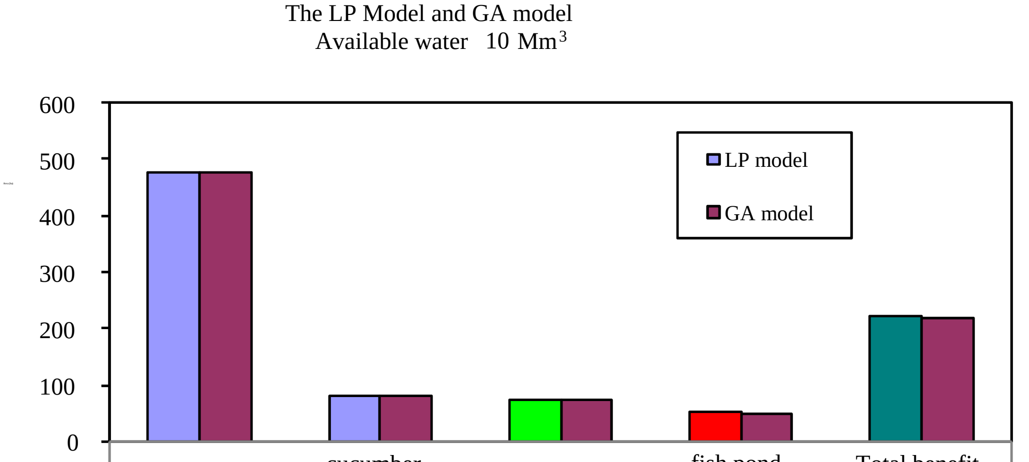
Figure 38 Evapo-transpiration and Percolation

Table 16 Crop water requirement rate of each crop for seasonal cultivation

Cultivation crops	Crop Water Requirement ($m^3.ha^{-1}$)	Yield ($kg.ha^{-1}$)	Crop price ($US\$.kg^{-1}$)	Benefit ($US\$. ha^{-1}$)
rice	12,945.8	3,284	0.3~ 0.4	320
cucumber	5,938	8,688	0.15~ 0.2	310
maize	4,604.6	5,518	0.1~ 0.2	124
fish pond	8,840.7	2,070	1.0~ 1.5	660

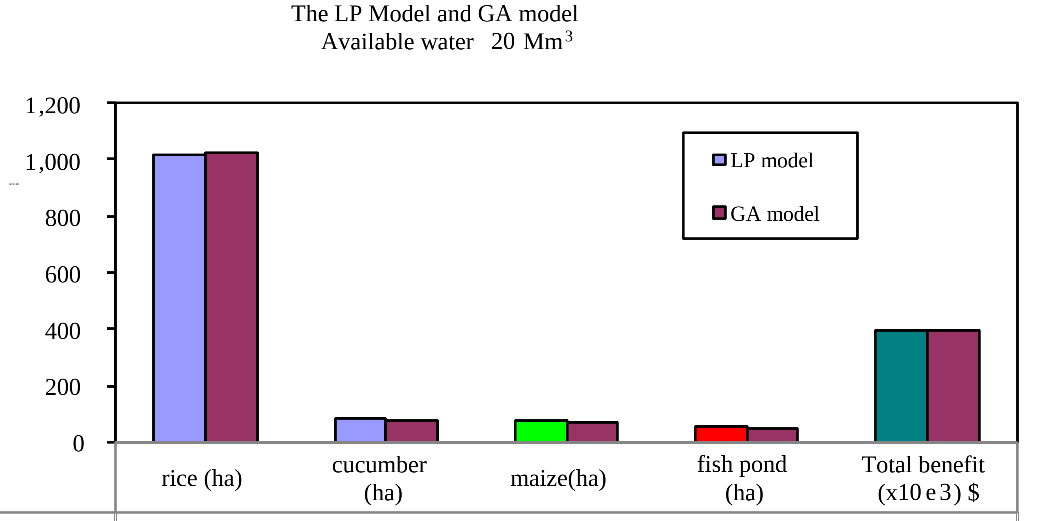
In this study, the efficiency of the GA model that can take into account of multi-functioned paddy fields is presented. For this reason, the mono-functioned character of the irrigation project is considered for comparing the case study. These amounts of available water, 10, 20, 30, 40, and 50 Mm^3 were applied to the develop GA model for finding optimal crop pattern.

Figures 39 to 43 shows the optimum crop pattern of the proposed GA and LP models (using multi-functioned character) for the available water of 10, 20, 30, 40, and 50 Mm^3 respectively. The crop patterns of the GA and LP models are appropriately for the targeted irrigation areas of the project for all provide water. The results have shown that the proposed GA with multi-functioned character can provide the optimal crop pattern with the maximum benefit. The obtained patterns of the irrigation project were then compared with the existing crop patterns of the LP model. The crop patterns from the both techniques were agreed well. Furthermore, the obtained crop pattern can be utilized for efficient planning of irrigation system in Lao PDR.



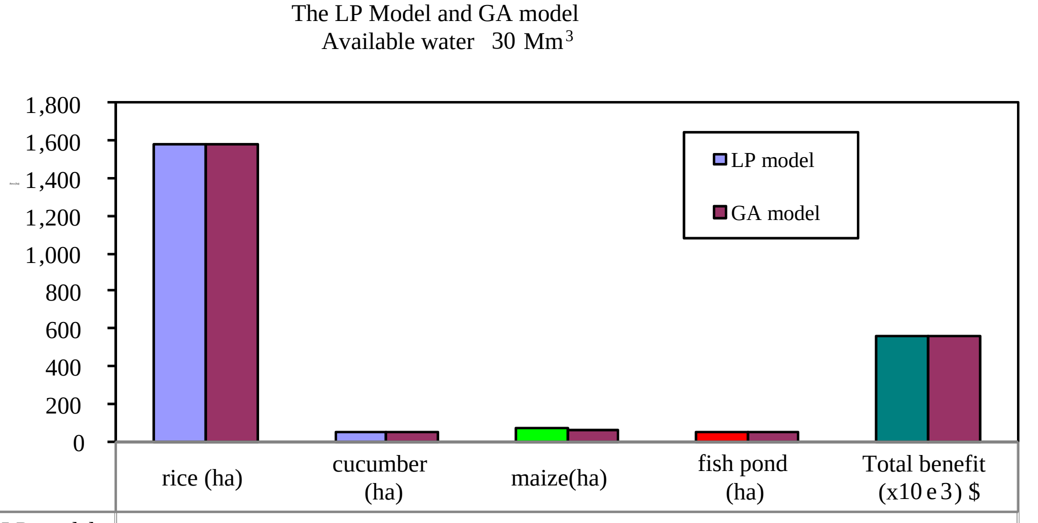
	rice (ha)	cucumber (ha)	maize(ha)	fish pond (ha)	Total benefit (x10 e 3) $
LP model	477 .23	82 .10	72 .70	51 .00	220 .84
GA model	476 .00	82 .10	72 .70	51 .00	220 .45

Figure 39 Optimum crop pattern of the GA and LP models using water 10 Mm^3



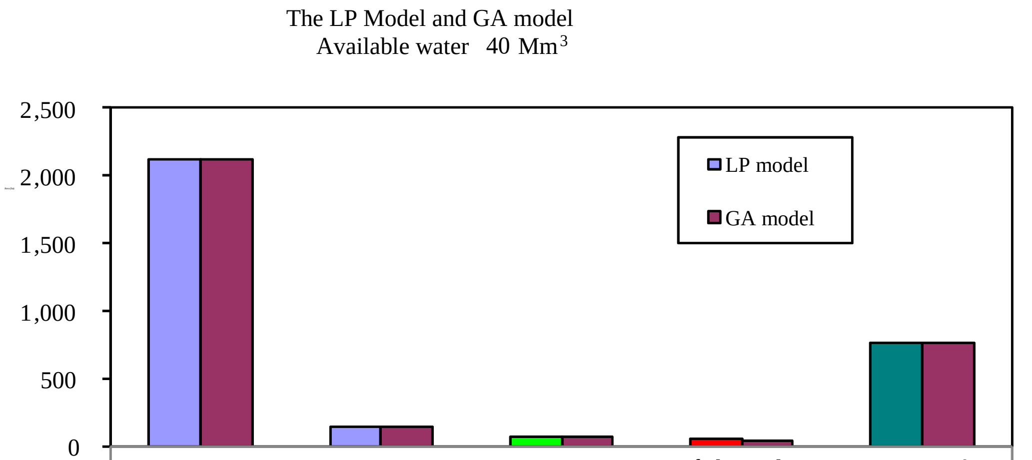
	rice (ha)	cucumber (ha)	maize(ha)	fish pond (ha)	Total benefit (x10 e 3) $
LP model	1,017 .97	82 .10	72 .70	51 .00	393 .88
GA model	1,020 .22	81 .10	72 .30	51 .00	394 .24

Figure 40 Optimum crop pattern of the GA and LP models using water 20 Mm^3



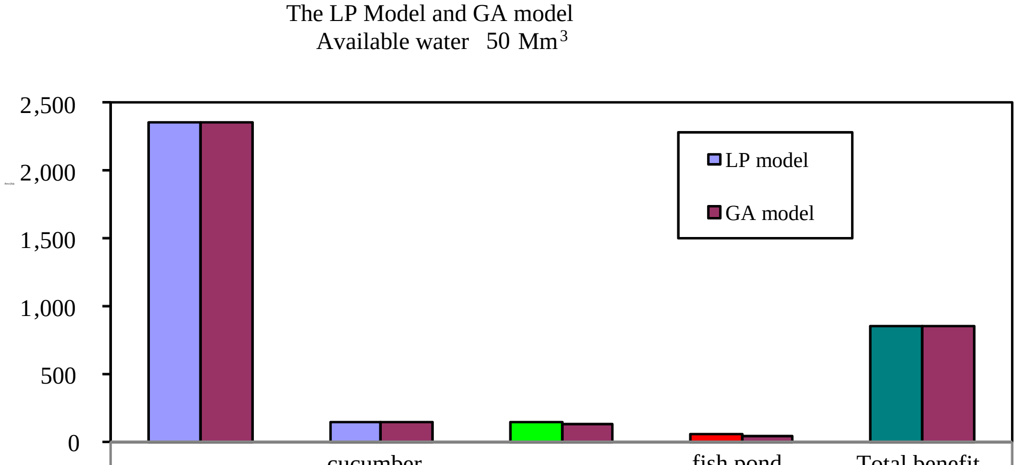
	rice (ha)	cucumber (ha)	maize(ha)	fish pond (ha)	Total benefit (x10 e 3) $
LP model	1,574 .69	57 .95	65 .65	51 .00	563 .67
GA model	1,573 .80	57 .30	66 .40	51 .00	563 .27

Figure 41 Optimum crop pattern of the GA and LP models using water 30 Mm^3



	rice (ha)	cucumber (ha)	maize(ha)	fish pond (ha)	Total benefit (x10 e 3) $
LP model	2,115 .32	140 .50	65 .65	51 .00	762 .26
GA model	2,116 .00	140 .50	66 .40	51 .00	762 .57

Figure 42 Optimum crop pattern of the GA and LP models using water 40 Mm^3



	rice (ha)	cucumber (ha)	maize(ha)	fish pond (ha)	Total benefit (x10 e 3) $
LP model	2,349 .00	140 .50	138 .35	51 .00	846 .05
GA model	2,349 .00	140 .50	138 .35	51 .00	846 .05

Figure 43 Optimum crop pattern of the GA and LP models using water 50 Mm^3

Table 17 shows the gross benefit of the scenario using the GA and LP model. The results show that both models provided gross benefit closely.

Table 17 The gross benefit of the scenario using the GA and LP model

Request Area (ha)	Available Water (MCM)	Total benefit (million kip)	
		LP model	GA model
2,400	10	220.84	220.45
	20	393.88	394.24
	30	563.67	563.27
	40	762.26	762.57
	50	846.05	846.05
	54	846.05	846.05

The table 18 presented the cropping patterns obtained by both the methods with available release water 20 Mm^3.

Table 18 Deviation obtained by using the GA and LP model

No	Crops	Crop Area (ha)		Percent Deviation
		LP	GA	(%)
1	Rice	1,017.97	1,020.22	0.22
2	Cucumber	82.10	81.10	1.23
3	Maize	72.70	72.30	0.55
4	Fish pond	51.00	51.00	0.00
Total irrigated area		1,223.77	1,224.62	0.07
Net Benefits (x10e3)$		393.88	394.24	0.09

4.6 Discussion

Efforts are also made to compare the solution of GA model with developed LP model. Cropping patterns obtained by both the methods are presented in Table 18. Considerable deviations between the two methods are observed such as available release water 20 Mm^3, 0.22% for Rice and 1.23% for Cucumber. Maximum benefits obtained by LP solution are US$ 393,880 and US$ 394,240 by GA. The results show that both models provided gross benefit closely. Thus, the obtained patterns of considering multi-functioned are corresponding to the available land areas of the suitable main canal zone. Genetic Algorithms is found to be an effective optimization tool for irrigation planning and can be used for more complex systems involving non-linear optimization.

Chapter 5

Conclusion

This chapter presents the conclusion and discussion of the Mathematical Model for estimating varied irrigation efficiency, Linear Programming for finding an optimal cropping pattern for irrigation planning and using Genetic Algorithm model for finding of the optimum-multi criteria irrigation water management in Nam Houm Irrigation Scheme, Naxaythong district, Vientiane capital, Lao PDR.

5.1 Conclusion

After analyzing the results of the Mathematical Model technique for estimating varied irrigation efficiency, the following conclusions were drawn. It is showed that the varied irrigation efficiencies from the Mathematical Model are closed to the actual irrigation efficiencies all series of variables input. It indicated that the varied irrigation efficiency using mathematical model is more precise. Consequently, the parameters of multiple regression function with all variables input of the model is appropriately to find the varied irrigation efficiency for irrigation planning.

The results of the developed Linear Programming model with considering multi-functioned of crop water requirement and crop yield for allocating the available land area. A sensitivity analysis of varied irrigation efficiency, seasonal release, irrigated area and crop yield in the LP model was taken into account in the study. The proposed LP model gave the optimum crop pattern with gross dry-season benefit that corresponding seasonal available water and suitable for actual irrigated area. It provided the higher benefit as compare to the LP model considering mono-functioned character. Multi-functioned character of scenario in term of crop water requirement and crop yield in the LP model has affected to the cropping patterns. The varied irrigation efficiency that used in irrigation planning provided the optimal crop pattern that can be given the higher gross benefit.

In this study, the most significant advantage of the technique for finding of the optimum-multi criteria irrigation water management was used Genetic Algorithm model by considering multi-functioned of crop water requirement and crop yield. The results gave the optimum crop pattern with gross dry-season benefit that corresponding seasonal available water and suitable for actual irrigated area. The model provided gross benefit closely to the gross benefit of the LP model.

5.2 Results of Analysis from the Mathematical Model

1. The mathematical model was evaluated by considering the coefficient of correlation (r) and coefficient of determination (R^2) which defined based on the actual irrigation efficiency and the estimated irrigation efficiency of all variables input

2. The coefficient of correlation (r) of relationship between irrigated area, participation of stakeholder in water resources management, available inflow and product cost (X_1-X_2-X_3-X_4) highest values is 0.940 of all variables input and also the coefficient of determination (R^2) of all variables is highest values of 88.3% respectively.

3. The least value of coefficient of correlation (r) is 0.729 of total irrigated area and inflow relationship(X_1-X_4). and also the coefficients of determination is 52.3%.

4. The power regression equation of mathematical model for relationship between irrigated area, participation of stakeholder in water resources management, available inflow and product cost (X_1-X_2-X_3-X_4) is near non-linearity if the comparison between others relationships with the values of exponent of (Xi) and the coefficients of determination (R^2)

5. The results also showed that the varied irrigation efficiencies are closed to the actual irrigation efficiencies all series of variables input. It indicated that the varied irrigation efficiency using mathematical model is more precise.

5.3 Results of Stakeholders Involved in Water Management

The stakeholders involved in water management presented a water resources linking issue of concern such as system infrastructures, environmental change, water allocation, assessment of water requirement, flow measurement and responsibility of stakeholders.

It is found from the results that water requirement is appraised using all parameters conducted in the fields such as evaporation, ETo, rainfall, crop coefficient, evapotranspiration, percolation, identify actual planted area, cropping pattern and crop calendar. The water management appraisal was conducted to stakeholders involved in water management in the project considering organization chart, responsibility of stakeholders and level of water management.

Water allocation plan is made for dry- season cultivation only, but also not provided for wet season cultivation. However, the plan is fixed with few changes to the piratical situation of water allocation and actual water requirement in each cultivation stage. An active monitoring of water allocation was also not found in this project.

The observation data show that, the reservoir is operated mainly for dry season cultivation, but rarely operated during the wet season cultivation, except land preparation and transplanting and dry spell of the rain cases. The constraints of the project can be summarized as follows; limited budget, limited funds, limited experience and capability of staff, poor condition of irrigation infrastructures, insufficient vehicles to facilitate work, weaknness in water user groups (WUGs) functioning.

The results of the focal group discussions and interviews were shown that the main problems in the area are low production, insufficient water supply and high cost of production. The suggestion to improve this situation includes provision or introduction of improved farming technology through training and extension and improved water management. The recommended solutions were to include strengthening of WUGs through intensive education and to involve membership, to improve financial transparency, to implement roles, rules and regulations (RRR) strictly. The poor condition of irrigation facilities were resolved by repairing irrigation canals and structures, strict implementation of the RRR and increase of repair funds through better Irrigation Service Fees (ISF) collection.

5.4 Results of Analysis from the LP Model

1. The crop patterns of the proposed LP model for the available water of 10, 20, 30, 40, and 54 $Mm^3$are appropriately for the targeted irrigation areas of the project for all provide water. For crop patterns of existing LP model (Mono-functioned character) are unsuitable for the targeted irrigation areas, because obtained patterns are larger and used more water than the proposed LP model.

2. The results from the proposed LP model show that the model with multi-functioned character of project provided gross benefit higher than the model with mono-functioned characters of project for all cases.

3. The obtained patterns of considering multi-functioned are corresponding to the available land areas of the suitable soil type, while the obtained patterns of mono-functioned consideration that having only rice and cucumber area are not suitable for the availability of land areas.

4. The varied irrigation efficiency of 0.4, 0.5, 0.6, 0.7 and 0.8, and available release water from reservoir of 10 Mm^3 (1 Mm^3 = 10^6 m^3), 20 Mm^3, 30 Mm^3, 40 Mm^3 and 50 Mm^3 were used to test the efficiency of the proposed model. The results show that the proposed model with varied irrigation efficiency (V-Multi) provides higher net benefit than the model of constant irrigation efficiency (C-Multi) for all cases.

5. The optimal crop pattern of the develop LP models for the available water of 10, 20, 30, 40 and 50 Mm^3 (1 Mm^3 = 10^6 m^3). The crop patterns of the LP model are approximately the targeted irrigation area of the project when having high available water.

6. The variation of Multi-functioned character has a large impact on the optimal solution. For this reason, LP model with multi-functioned character of land area is appropriate for finding optimum crop pattern.

5.5 Results of Analysis from GA Model

1. The available water of 10, 20, 30, 40, and 50 Mm^3 were used for finding the optimum crop pattern of the proposed GA and LP models by using multi-functioned character.

2. The constraints of the model were divided into two categories including water constraint and land area constraint. The water constraint considered the irrigation efficiency from the mathematical model, due to the varied irrigation efficiencies were closed to the actual irrigation efficiencies all series. The land area constraint considered the multi-functioned character of paddy field of the suitable soil type for cultivation each crop, the zone area is divided into several suitable soil types, the summation of all zone area is not greater than the available total area of scenario.

3. The varied irrigation efficiency of 0.4, 0.5, 0.6, 0.7 and 0.8 and available release water from reservoir of 10 Mm^3 (1 Mm^3 = 10^6 m^3), 20 Mm^3, 30 Mm^3, 40 Mm^3 and 50 Mm^3 were used to test the efficiency of the proposed GA model.

4. The crop patterns of the GA and LP models are appropriately for the targeted irrigation areas of the project for all provide water.

5. The results have shown that the proposed GA with multi-functioned character can provide the optimal crop pattern with the maximum benefit.

6. The obtained patterns of the irrigation project were then compared with the existing crop patterns of the LP model. The crop patterns from the both techniques were agreed well.

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Appendix

Appendix A
Questionnaires

A. Technical Information for the project had been constructed

Province:.. District:...
Scheme:.. Village:...
Name of Recorder:.. Date:...

Question	Numerical	Explanation
I System Information		
1. Water Source		
a) Name of River and Status:		
b) Maximum Discharge (cms)		
c) Minimum Discharge (cms)		
d) Describe the situation of the water source during the first construction		
e) Describe the water source at present		
2. Type of Scheme		
a) Gravity Weir		
b) Dam/Reservoir		
c) Pump		
d) Traditional		
e) Others		
2.1 Gravity Weir/Dam		
a) Type		
b) Capacity (cu.m)		
c) Catchments Area (km2)		
d) Storage Area (km2)		
e) Live Storage (cu.m)		
f) Dead Storage (cu.m)		
g) Gross Storage (cu.m)		
h) Classification of dams		
i) First Construction date		
Funding source and cost in Kips		
j) First Rehabilitation date		
Funding source and cost in Kips		
k) Second Rehabilitation date		
Funding source and cost in Kips		
l) WUA/WUG participation?		
m) Design discharge (cms)		
n) Dimensions:		
Height (m)		
Width (m)		
Length (m)		
o) Present Status:		
p) Top bank elevation (masl)		
q) Flood (Full) Supply level (masl)		
r) Side slope		
2.2 Pumping Station		
a) Type and status		
Pontoon pump		
Axial Flow Pump		
Others		
b) HP		

Question	Numerical	Explanation
c) capacity		
d) outlet discharge (cms)		
e) pump efficiency (%)		
f) suction/delivery head (m)		
g) Installation year		
h) exhaust hours		
i) Operation and maintenance status		
j) Suction pipe		
k) Outlet (discharge) pipe		
l) electric system		
switch board		
electric wires etc.		
m) Pumping hours record for each pump		
n) Water level record		
o) Water gauging status (if any)		
p) Min Design Water level (masl)		
q) Max Design Water level (masl)		
r) Elevation of Motor installation		
s) First Construction date		
Funding source and Cost in Kips		
t) First Rehabilitation date		
Funding source and Cost in Kips/US$		
u) Second Rehabilitation date		
Funding source and Cost in Kips/US$		
v) WUA/WUG participation?		
w) Power cost for pumping		
1) Kip per kWh		
Year		
2) Kip per season		
Year		
3) Kip per hectare		
Year		
2.3 Intake		
a) Dimensions:		
Height (m)		
Width (m)		
Design discharge (cms)		
Inlet Elevatiom (masl)		
Present Status:		
Dia. of Pipe and Numerical		
b) Facilities Structures		
2.4 Spillway		
a) Design discharge (cms)		
b) Crest Elevation (masl)		
c) Dimensions:		
Height (m)		
Width (m)		
d) Gates		

Question	Numerical	Explanation
3 Irrigable and flooded area (ha)		
3.1 Irrigable Area		
a) Total area per design layout		
Wet season irrigable area		
Dry season irrigable area		
b) Highest wet season irrigated area		
Year		
c) Highest dry season irrigated area		
Year		
d) Actual of dry season irrigable area		
Year 2008-09		
e) Total of wet season irrigable area		
f) Wet season irrigated area		
1)		
2)		
3)		
g) Dry season irrigated area		
1)		
2)		
3)		
3.2 Flooded area		
a) Highest flooded area		
b) Year		
c) Duration of flooding		
d) Flooded status		
4 Canal system and O&M road		
4.1 Canal system		
a) Main Canal		
Type		
Length (m)		
Width (m)		
Design Water depth (m)		
Design discharge (cms)		
Water delivery status		
Canal shape status and efficiency (%)		
Canal structures and status		
.- Division boxes		
.-Checks		
.-Drops		
.- Drain culverts		
.-Turnouts		
.-Control gates		
.- etc		
b) Secondary canal		
Type		
Length (m)		
Width (m)		
Design discharge (cms)		

Question	Numerical	Explanation
Water distribution status		
Canal shape status and efficiency (%)		
Canal structures and status		
.- Division boxes		
.-Checks		
.-Drops		
.- Drain culverts		
.-Turnouts		
.-Control gates		
.- etc		
c) Tertiary canal		
Type		
Length (m)		
Width (m)		
Design discharge (cms)		
Water distribution status		
Canal shape status and efficiency (%)		
Canal structures and status		
.- Division boxes		
.-Checks		
.-Drops		
.- Drain culverts		
.-Turnouts		
.-Control gates		
.- etc		
d) On farm system and status		
4.2 O&M road and status		
a) Main Canal		
Length (m)		
Width (m)		
b) Secondary canal		
Length (m)		
Width (m)		
c) Tertiary canal		
Length (m)		
Width (m)		
4.3 Drainage systems		
a) Main Canal		
Length (m)		
Width (m)		
5 Document to be collected if available		
a) System map		
b) Canal layout		
c) Cadastral map (if any)		
d) On farm system (if any)		
e) Design data		
II Operation and Maintenance		
1. O&M Planning and implementation		

	Question	Numerical	Explanation
a)	How are O&M plans for the system prepared? When? By whom?		
	Cropping schedule		
	Water distribution schedule		
	Repair and maintenance schedule		
	Method for water distribution		
	1) continuous		
	2) rotation		
	3) others		
	Collection of fees schedule		
b)	Does the WUA prepare seasonal O&M plan ? (Look at prepared plans)		
c)	Are the WUA O&M plans implemented efficiently? Why?		
	Cropping schedule		
	Water distribution schedule		
	Repair and maintenance schedule		
	Method for water distribution		
	1) continuous		
	2) rotation		
	3) others		
	Collection of fees schedule		
d)	Does the WUA prepare seasonal O&M report ? (Review prepared O&M report)		
e)	How are the report prepared? By whom? Where reports submitted?		
2. Repair and Maintenance of irrigation system			
a)	How is the maintenance responsibility of the WUA done ? Do individual farmers contribute labor, materials, money, etc.?		
	How much labor is contributed by each household?		
b)	What was the largest repair job undertaken by community-either paid or implemented by WUA?		
c)	What are the main problems with the irrigation now :		
	1) Headwork		
	2) Pump		
	3) Electric system		
	4) Canal system		
	5) Facilities structures		
	6) Others		
d)	In case of emergency repairs of systems damaged by flood or" force majeure", how are the funds provided? How much? How is the repair implemented?		
3. Operational condition of irrigation system: (very functional, fairy functional, poor, not functional)			

Question	Numerical	Explanation
a) Canals		
b) Headwork or pump		
c) Electric system		
d) Canal structures		
e) Control gates etc.		
4. Assistance from Province/District		
a) What assistance are given by the DIS on the O&M of the system?		
b) How frequent do DIS staff visit the system?		
c) What assistance are given by the PIS on the O&M of the system?		
d) How frequent do PIS staff visit the system?		

Person Interview: Date:

1)

2)

B. Social - Economical and Agricultural Data and Information

Province. . . . . ………………………… District. . . . . ……………

Scheme . . . . Village:...

Name of Recorder………………………………… Date:...

	Question	Nurmerical		Explanation
	Demography, labor and land utilization information	Total	Village	
1	**Demographic Data**			
1.1	Number of Households			
1.2	Total famiies			
1.3	Total population			
1.4	Women			
1.5	Total Main labor			
1.7	Total secondary labor			
1.8	Total Government staff (persons)			
1.9	Temporary labor selling			
1.10	No. of villagers go to wotk away from village			
2	**Off - Farm activity (No. of person/ season/ income. . .)**			
2.1	Household based small shop services			
2.3	Weaving (No. of weaving ateliers)			
2.4	Tailor			
2.5	Barber/ cosmetic shop			
2.6	Natural fishing (in Namhoume reservoir)			
2.7	NTFP collecting			
2.8	Fire wood / Charcoal			
2.9	Mechanical services (Bike, Motorbykes and tyre reparing)			
2.10	Rice mills / milling services			
2.11	Tractorists/ land preparation services			
2.12	Transport / vehycle services			
2.13	Vaccine suppliers / Vaccinators			
2.14	House building / Carpenter			
2.15	Restaurant services (Noodle soup and soft drink service)			
2.16	Bamboo handicraft			
2.17	Smith			
3	Total area implemented during last 3 years			
3.1	Dry season rice area			
-	No of families planted 2008 - 2009			
-	Area 2008 - 2009			
-	No of families planted 2007 - 2008			
-	Area 2007-2008			
-	No of families planted 2006 - 2007			
-	Area 2006 - 2007			
3.2	Wet season rice cultivation (main crop)			
-	No. of farmers planted wet season rice			

Question		Nurmerical		Explanation
	a. 2009			
	b. 2008			
	c. 2007			
4	Average rice yield in last 3 years			
4.1	**Dry season**			
	a. 2008 - 2009			
	b. 2007 - 2008			
	c. 2006 - 2007			
4.2	**Wet season**			
	a. 2009			
	b. 2008			
	c. 2007			
	d. What is the main problem existed? How could it being resolved by whom?			
5	What non rice crops are planted successfully in the irrigation scheme during last 3 dry season years (Name of crops)			
5.1	Sweet corn farmers			
-	Sweet corn area (ha)			
5.2	Cucumber farmer			
-	Cucumber area (ha)			
6	**Upland agriculture**			
6.1	Upland rice farmer			
-	Upland rice area (ha)			
6.2	No of fruit tree planting farmers			
-	Area of fruit tree planted			
6.3	Ruber tree planting farmers			
-	Ruber tree area (ha)			
6	Accessibility to Inputs supplier (Name of supplier/ Location/ Distance/ Quantity/ Price/ Quality/ Relationship. . .)			
6.1	# Some farmers buy the R1 or R2 from NARC directly(Naphok Research Station)			
6.2	Some seeds were goten from the relatives			
6.3	APB had supplied fertilizer in some years but to expensive.			
	Any Problem existed/ How could it being resolved by whom ?			

Question		Nurmerical		Explanation
7	Accessibility to Credit (Name of service/ Locatio/ Distance/ Amount of credit per season or year/ I - rate/ Relationship. . .)			
7.1	APB			
7.2	Village Saving and development Fund			
	Any Problem existed/ How could it being resolved by whom ?			
8	Accessibility to Market (Type of ware/ Name of Buyer/ Market name/ Location/ Distance/ Quantity/ Price/ high Season)			
8.1	Glutinous paddy rice			
8.2	Ordinary paddy rice (KMDL 105)			
8.3	Glutinous white rice			
8.4	Ordinary white rice			
8.5	Sweet corn			
8.6	Cucumber			
9	**Animal husbandry (No. of family/ animal heads/ ....)**			
9.1	Baffalo			
9.2	Cattle			
9.3	Pig			
9.4	Goat			
9.5	Poultry			
9.6	Fish raising in pond (No. of Farmers)			
-	No. of Ponds			
-	Total Pond area (ha)			
-	No. of fingerling released			
10	**Animal Farms(No. of Farm/ size/ Capital / Return. . .)**			
10.1	No of pig raising farm			
-	No. of pig in the farm			
10.2	No. of Chicken farm			
-	No. of chicken in the farm			
10.3	No. of Fish farm (Gage fish raising)			
	No. of gages			
	No. of fingerling released			
11	**Land tenure and utilisation**			
11.1	No. of permanent member of WUA not cultivate their land during the dry season			
-	Area (ha)			
11.2	No. of permanent member of WUA not cultivate their land during the Wet season			
-	Area (ha)			

	Question	Nurmerical		Explanation
11.3	No. of permanent member of WUA give their land to other to borrow / lease during the dry season			
-	Area (ha)			
11.4	No of farmers borrow / lease the land for dry season rice cultivation			
-	Area (ha)			
11.5	No of farmers borrow / lease the land for crops cultivation (Cucumber and sweet corn)			
-	Area (ha)			
12	Average income kip / person.month			
	US$			

Province. . . . .
District. . . . .
Scheme . . . .

B.1 Economic Performance of ……........... (Production) checklist , year . . . .

Name of Farmer :. . . . . Ban . .. . Plot No/ Location.. . . . . soil Type. . . . .(Unit . . . .)

No.	Item	No.	Unit	Price	Value	Remark
I	Expenditure					
(i)	**Inputs**					
1	Fry					
2	Manure					
3	Bio - fertlizer					
4	Lime					
5	Water					
6	Chemical Fertilizer					
-						
-						
7	Pond building / repairing					
8	Intertest fee for credit					
9	Irrigation Mntg Fee					
10	Fencing materials					
-	Barbed wire					
-	Woods					
11	Other (clarify)					
-						
-						
(ii)	**Labor and hire cost**					
1	Carring the pond					
2	Fencing					
3	Irrigating					
4	Improving water quality					
5	Harvesting - Processing					
6	Transporting and saling					
7	Other (clarify)					
-						
-						
-						
-						
II	Return					
1	Fresh product					
2	Processed product					
III	Balance					

Note

-1 Irrigation Mntg Fee = (Electricity + O&M + CIDF)

C. Financial/ Cost Recovery and Information

Province:... District:..................................

Scheme:.. Village:...................................

Name of Recorder:... Date:......................................

Question	Numerical	Explanation
I. Irrigation Service Fee		
1 How was the ISF calculated? Who were involved?		
2 How is ISF collection done? Who are involved? Who keeps/manage the collection?		
3 Allocation of ISF, %		
a Electricity/fuel		
b Irrigation system repair & maintenance		
c Personnel services (honoraria, salaries, etc.)		
d Office supplies and equipments		
e Miscellaneous		
4 For the last 3 years. How much was the ISF collectibles? (See Table O-10*)		
5 For the last 3 years. How much was the ISF collection? (See Table O-10)		
6 Accumulated balance of collected ISF at present, Kips (see Table O- 10)		
II. Village Development Fund		
1 Village Development fund collected? Rate/hectare		
a District, %		
b WUA, % (allocated as:)		
1) Repair and maintenance		
2)		
3)		
4)		
2 How is VDF collected? Who collects?		
3 How is the VDF allocated?		
a District, %		
b WUA, % (allocated as:)		
1)		
2)		
3)		
4 For the last 3 years. How much was the VDF collectible? (see Table 11*)		
5 For the last 3 years. How much was the actual VDF collection? (see Table 11)		
6 How much is the present balance of collected VDF in Kips? (see Table 11)		

Question	Numerical	Explanation
III. O&M Cost		
1 O&M Cost (refer to table T-1*)		
2 How much WUA money had been spent on repairs and maintenance over past 3 years		
1) 2009		
2) 2008		
3) 2007		
3 Government funds provided for repairs and maintenance over past years?		
a Last 3 years		
1) 2009		
2) 2008		
3) 2007		
b 5 years		
c 10 years		

Remarks:

* In separated documents

D. WUA Development and Organization Data

Province:... District:.................................

Scheme:.. Village:.................................

Name of Recorder:.. Date:...................................

	Questions	Numerical	Explanation
I.	**Provincial/District/Village Government Support**		
1	Provincial Irrigation and Extensions Staff and positions specified (Table 1*)		
2	District Irrigation & Extension Staff and positions specified (Table 2*)		
3	Provincial Irrigation and Extension Allocation/ Expenses for the last 3 years (Table 1)		
4	District Irrigation and Extension Allocation/ Expenses for the last 3 years (Table 2)		
5	How frequent do Irrigation and Provincial Extension Staff visit irrigation communities		
6	How frequent do District Irrigation and Extension Staff visit irrigation communities		
7	Support given by province to irrigation communities		
8	Support given by District to irrigation communities		
9	What is the role of the village authority		
10	What is the role of women/LWU		
11	What is the role of Senior Citizen Committee		
12	For what does the district utilize the VDF remitted by WUAs?		
14	What problems constrain the PAFSO? Manpower sufficiency, Manpower capability, Budget, etc.		
15	Recommendations to improve PAFSO service?		
16	What problems constrain the DAFEO? Manpower sufficiency, Manpower capability, Budget, etc.		

Questions		Numerical	Explanation
17	Recommendations to improve DAFEO service?		
II. System Turnover			
1	In general, how are irrigation projects for construction/rehabilitation identified, planned and constructed in the province? Do Districts/ Province have ready profile of pipeline subprojects that is updated annually?		
2	Describe the procedure of IMT implementation in the province		
3	System turned-over? Full? Partly (Joint Management)		
4	When was turn-over made?		
5	For IMT systems: Specified roles/responsibilities of the government (DAFSO/PAFSO) and WUA in the IMT contract (get copy of contract)		
6	What technical assistance is being provided by the government (DAFSO/PAFSO) after IMT		
III. WUA Organization and Development			
1	Is there are WUA/WUG?		
2	When was it organized? How long?		
3	Who assisted in establishing the WUA		
4	Who are listed as members? HH, Husband, Wife?		
5	How many registered members		
6	How many of the members are women? (Widows or single women?)		
7	Ethnic distribution of membership		
	a Lao Soung		
	b Lao Moung		
	c Lao Loum		
8	Is the WUA registered? When? For big schemes like Nam Houm a Table is Necessary.		
9	What was the involvement/participation of the WUA/farmers during the project identification, planning and construction (original construction)		
10	What was the participation of the WUA during the rehabilitation(s) of the system - planning and construction		
11	Membership of the WUA Executive Committee (EC) per position (note on remarks if male or female)		

Questions		Numerical	Explanation
	a WUA Chief (male)		
	b Deputy WUA Chief (male)		
	c Accountant (male)		
	d Cashier (male)		
	e Head Agriculture Production (male)		
	f Head Irrigation (male)		
	g Secretary/Gender (Female)		
	h 4 Irrigation Block Leaders LMC - (Males)		
	i 4 Irrigation Block Leaders RMC - (males)		
	Total Women in the WUA EC		
12	Advisers		
	a Head of village senior citizen		
	b Previous WUA Head		
13	Steering Committee (kana sinam): 3 Village Chiefs		
14	Does the WUA convene an Annual General Meeting?		
13	WUA Trainings received		
	a Setting up WUA (WUA Management)		
	b Irrigated agriculture		
	c Irrigation System O&M		
	d Accounting (Financial Management)		
14	Who planned and conducted the above trainings? Financed by whom?		
15	How were the trainings conducted? (classroom, OJT, Field visit, tutorial, etc.)		
	a Setting up WUA (WUA Management)		
	b Irrigated agriculture		
	c Irrigation System O&M		
	d Accounting (Financial Management)		
16	Were the trainings successful in developing the capability of the WUA? Why?		
	a Setting up WUA (WUA Management)		
	b Irrigated agriculture		
	c Irrigation System O&M		
	d Accounting (Financial Management)		
17	Suggestions to improve the trainings		
18	Other trainings needed? (which were not given)		
19	WUA have copy of by-laws or Roles, Rules and Regulations (RRR)?		
20	Does the WUA have separate Irrigation System O&M policies?		
21	Is the RRR/policies efficiently implemented? How and why if not implemented?		

Questions		Numerical	Explanation
22	Does the WUA provides loans to members out of its funds?		
23	Are committee members paid – by position		
	a		
	b		
	c		
	d		
	e		
	f		
	g		
	h		
	i		
24	WUA bank accounts? How many and for what?		
25	Annual budget of the WUA		
	a Does the WUA prepare annual budget?		
	b Who prepares?		
	c How is it approved? (members consulted?)		
	d Who approve?		
	e Approved budget disseminated to members? How?		
26	Does the WUA have an accounting system		
27	Are the accounts complete and transparent. How is transparency promoted (reports, meetings?)		
	What is the current WUA bank balance		
	Are the accounts audited or checked each year? Who audits the WUA account?		
	Are the accounts posted for members to see? Or are these discussed in a meeting?		
28	Financial report of WUA		
	a Monthly?		
	b Annual?		
	c Who prepares?		
	d Who reviews and audit?		
	e Percentage of expenses		
	Personnel services, %		
	Office supplies, equipments, materials, %		

Remarks:

* In separated documents

Appendix B
Rainfall Data

Monthly Rainfall (mm) - Vientiane Meteorology Station. Altitude 171 m
1923/50 from Water Balance Study 2005 (DMH)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max
1951	27.4	-	25.5	133.9	245.9	284.0	350.3	242.0	333.8	165.8	7.6	0.1	1,816.3	73.2
1952	-	1.0	44.0	49.0	193.3	220.5	252.0	578.0	462.0	69.0	8.0	-	1,876.8	130.0
1953	50.4	65.1	7.5	24.4	217.3	365.8	196.7	291.4	390.6	31.3	108.6	-	1,749.1	101.4
1954	22.9	3.3	-	35.5	389.4	203.0	122.1	447.7	237.0	64.9	-	4.7	1,530.5	106.7
1955	-	0.6	24.1	153.6	189.6	272.1	263.5	300.2	344.2	15.2	3.0	-	1,566.1	132.9
1956	-	45.8	46.1	134.3	388.3	354.2	212.2	428.1	384.9	9.0	1.2	-	2,004.1	101.3
1957	-	1.3	12.1	56.4	172.7	355.7	292.5	274.3	200.1	83.7	10.0	-	1,458.8	85.0
1958	35.2	6.6	2.7	25.3	97.4	260.0	186.3	344.0	233.6	7.9	0.9	-	1,199.9	89.3
1959	-	16.2	78.9	125.4	228.7	209.1	435.7	219.5	672.7	-	-	-	1,986.2	138.7
1960	10.3	-	6.7	40.1	135.3	102.3	264.6	389.1	586.7	42.8	15.8	-	1,593.7	106.1
1961	-	29.9	40.5	59.6	377.7	441.5	134.3	326.8	516.5	138.8	-	-	2,065.6	121.2
1962	10.3	-	10.6	118.3	253.5	196.4	207.4	429.1	356.0	111.7	-	2.7	1,696.0	100.2
1963	-	-	17.4	56.5	155.3	306.3	279.2	188.7	182.3	106.1	30.3	6.3	1,328.4	106.6
1964	-	11.6	28.5	100.1	407.3	213.1	306.0	238.5	400.1	152.1	0.5	-	1,857.8	91.1
1965	-	8.4	-	241.5	309.8	298.5	265.8	391.8	327.7	64.6	12.5	-	1,920.6	112.0
1966	2.4	18.7	78.4	109.5	349.3	232.7	172.3	656.7	214.4	33.5	6.0	-	1,873.9	110.5
1967	2.3	12.6	6.0	94.2	159.9	221.8	327.3	209.8	488.9	-	21.2	-	1,544.0	137.3
1968	0.9	-	100.6	84.3	301.8	243.5	258.2	206.8	272.0	27.7	-	-	1,495.8	93.1
1969	19.6	-	42.4	40.9	204.3	295.9	402.1	128.9	247.9	49.9	14.3	-	1,446.2	134.8
1970	0.5	-	31.2	56.9	306.4	377.2	175.7	624.9	420.5	53.8	-	0.1	2,047.2	116.3
1971	-	7.3	13.9	34.1	294.0	274.8	289.4	226.4	163.4	103.5	0.8	18.2	1,425.8	84.7
1972	-	6.8	36.8	167.6	115.6	312.8	246.1	306.7	166.3	148.4	8.2	5.8	1,521.1	75.9
1973	-	-	37.0	36.4	308.3	200.7	298.6	263.9	361.3	25.7	-	-	1,531.9	96.2
1974	-	1.6	36.7	97.4	100.5	159.2	255.7	368.4	187.1	92.6	29.7	0.2	1,329.1	133.5
1975	23.5	26.3	13.2	21.8	347.0	473.9	177.5	430.4	289.7	194.4	8.5	-	2,006.2	94.0
1976	-	23.0	111.9	126.9	121.7	167.3	167.6	403.1	416.7	76.7	-	-	1,614.9	224.2
1977	15.2	-	35.1	69.0	151.9	231.0	211.1	174.8	190.3	26.5	16.5	22.8	1,144.2	95.4
1978	1.6	17.8	51.1	145.9	328.4	254.9	354.6	293.6	381.4	128.9	28.5	-	1,986.7	82.7
1979	-	21.0	0.1	61.8	344.7	333.3	150.1	117.8	253.1	19.2	-	-	1,301.1	81.2
1980	-	18.6	68.8	61.0	319.5	611.0	461.5	342.9	353.4	54.7	-	-	2,291.4	86.8
1981	-	0.3	19.6	124.2	311.1	238.5	635.0	210.0	224.8	117.8	40.5	-	1,921.8	181.0
1982	-	6.1	60.8	69.6	178.9	95.4	253.8	484.0	319.5	90.2	22.2	0.6	1,581.1	133.2
1983	53.1	5.7	-	58.1	97.6	243.8	217.9	360.8	247.4	67.9	-	7.2	1,359.5	115.0
1984	-	10.5	-	89.1	148.3	148.1	421.0	388.9	267.1	142.1	17.3	-	1,632.4	73.9
1985	24.8	64.7	4.9	10.8	135.3	223.5	257.4	191.9	258.8	81.4	-	-	1,253.5	82.2
1986	-	3.2	1.5	118.8	383.4	256.2	308.9	318.3	275.3	66.7	-	21.0	1,753.3	119.7
1987	-	13.9	101.1	127.0	63.6	473.8	175.0	356.0	260.7	93.4	3.2	-	1,667.7	162.0
1988	-	23.4	2.8	66.0	573.2	131.5	181.9	257.6	170.4	194.6	-	-	1,601.4	162.2
1989	23.6	-	63.0	85.6	200.8	165.1	132.5	421.4	459.7	99.3	-	-	1,651.0	91.8
1990	1.8	33.5	38.1	1.2	227.0	377.6	190.8	320.8	270.2	55.3	35.4	-	1,551.7	85.3
1991	-	-	49.3	76.7	250.0	67.3	232.0	313.5	301.7	31.8	-	9.2	1,331.5	80.6
1992	38.1	27.3	1.1	42.4	237.2	487.8	438.1	367.6	309.1	63.0	-	21.2	2,032.9	151.5
1993	-	4.7	3.9	21.0	362.0	387.8	248.0	235.8	197.9	7.2	-	-	1,468.3	150.4
1994	-	30.0	92.1	32.2	272.5	469.8	193.2	400.0	303.9	101.6	-	16.6	1,911.9	77.6
1995	-	13.6	4.7	70.8	217.4	260.9	567.9	586.6	160.6	118.0	2.8	-	2,003.3	134.6
1996	1.9	44.7	86.3	137.8	176.4	357.3	222.8	196.6	369.2	72.7	91.8	-	1,757.5	123.5
1997	7.1	2.3	55.2	132.8	49.5	211.8	502.4	337.0	121.2	179.9	0.4	-	1,599.6	85.5
1998	-	7.7	34.5	78.5	143.9	277.8	304.3	392.6	185.6	45.8	5.7	1.0	1,477.4	110.2
1999	3.7	-	26.0	204.7	514.1	289.4	278.4	241.0	531.9	93.7	5.3	4.0	2,192.2	161.6
2000	-	17.5	22.0	150.0	209.8	346.6	211.3	235.8	247.9	58.9	-	-	1,499.8	145.9
2001	1.5	-	76.5	32.3	354.9	177.5	314.2	340.5	277.0	80.9	3.7	-	1,659.0	80.5
2002	0.4	22.4	24.8	54.4	322.0	288.3	276.6	411.2	279.2	133.6	15.5	18.3	1,846.7	94.2
2003	8.4	27.7	73.8	111.8	169.8	384.8	130.1	235.8	297.2	41.6	-	-	1,481.0	92.2
2004	2.3	81.3	1.8	152.4	220.6	286.9	350.4	288.1	237.6	-	8.2	-	1,629.6	104.0
2005	-	6.2	41.9	50.0	138.5	338.0	237.1	417.4	372.0	28.9	37.5	0.3	1,667.8	82.9
2006	-	4.1	97.9	256.4	230.6	151.3	439.9	300.9	137.0	312.2	-	-	1,930.3	
2007	-	6.7	2.9	29.3	191.7	270.7	169.7	413.1	359.9	20.4	3.2	-	1,467.6	

Averages on 55 years---

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max
Averages on 55 years	6.8	14.1	35.0	86.8	243.8	278.6	273.8	331.0	306.6	78.9	11.0	2.8	1669.1	111.3
Standard deviation	13.1	18.1	30.8	50.8	110.8	107.6	108.5	117.4	114.6	51.1	20.7	6.3	262.2	30.9
Lambda coefficient	0.41	0.84	2.10	5.20	14.60	16.69	16.40	19.83	18.37	4.73	0.66	0.17	100.00	

Appendix C
Papers Publication

Technology and Innovation for Sustainable Development Conference (TISD2008)
Faculty of Engineering, Khon Kaen University, Thailand
28-29 January 2008

A Multi-Functioned Soil Type in LP Model for Irrigation Planning

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Abstract

The objective of this paper is to present an allocation LP model for irrigation planning in multi-functioned of paddy fields of the Nam Houm Irrigation Scheme, Vientiane capital, Lao PDR. The proposed LP model was applied to find the optimal crop pattern in dry-season (December-April). The irrigation project was divided into several sub-areas based on suitable soil type of each crop for representing the multi-functioned character. The existing suitable soil type of each crop was used to represent the multi-functioned character in term of water requirement and crop yield for each scenario. The records of seasonal flow, requested and actual irrigation area, crop water requirements, evaporation, percolation, and effective rainfall were used for this illustrative application. The results showed that the obtained crop pattern of the proposed model corresponded to the suitable soil type for cultivation crops. Furthermore, the results presented that the proposed model gave higher net benefit than the existing LP model considering mono-functioned character. The proposed LP model is feasible for finding the optimal crop pattern.

Keywords: Linear programming (LP), irrigation planning, cropping pattern.

1. Introduction

An Irrigation Project under poor irrigation planning is the one of the classical problems in water resources management. In particular, given the total available resources such as water, land area, production cost, one would like to know a cropping pattern of the irrigation project in order maximize the total profit. Before starting of each irrigation season, an Operation and Maintenance staff of an irrigation scheme should prepare appropriately of irrigation planning to ensure that required total of land-area from the farmers for each seasonal cultivation and how much water inflow to the reservoir, and to be distributed into paddy fields. Also the irrigation facilities and structures should monitor time to time. For this reason, the repair of irrigation canals and structures is necessary. Oppositely, the farmers need the have the optimum cropping pattern which will maximize the economic return. A linear programming (LP) is an optimization technique which widely used to allocate the limited water resources because of the proportionate characteristic of allocation problem.

One popular application of the technique in the water resources literature is to find an optimal seasonal crop pattern subjected to limit available resources i.e., land area, water, manpower and cost. The maximization benefit was set as the objective function based on the resources constraints. The constraint functions are linear equation for finding optimum crop pattern when given available water [1], [3], [8]. In addition, constant irrigation efficiency is used in the constraint LP model. A different portion of treated water from wastewater treatment and ground water is included into the water constraints of LP model [9]. For finding optimum crop water requirement when given available water [13]. A different portion price of irrigation water is considered in constraints of LP model [6], [7].

Often, most irrigation projects lacked satisfactory tools for finding the optimum crop water requirement for each crop pattern. The crop yield is usually affected by crop water requirement and physical soil type which suitable for cultivation of each crop. As a result the obtained pattern is inappropriately with soil type, so consequences are increasing production cost, using chemical fertilizer and pesticide, and increasing pollution.

The purpose of this paper is to propose an allocation LP model that can take into account multi-functioned paddy fields and multi-crop water requirements. The multi-functioned character of the irrigation project will be represented by dividing each crop water requirement and paddy fields into several crops and sub- areas based on suitable soil type for cultivation crop.

2. Model Formulation

The linear programming is used as a based model for finding optimal crop water requirements and optimal seasonal crop pattern. The model will be formulated to maximize benefit subjected to the limited resources on available seasonal water and suitable soil types of each crop. The obtained cropping pattern can be used for seasonal planning which considering the multi-functioned characters of paddy fields. The objective function of the model can be presented as:

$$MaxZ_j = \sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K} NB_{hik} X_{hijk} \quad (1)$$

where Z_j is the gross benefit of the scenario during the season *j*, *h* is sub-area index of the scenario (*h=1,2,3,....H)*, *i* is soil type index (*i=1,2,3...I)*; *j* is seasonal index *j*, *k* is crop type (*k=1,2,3...K)*, NB_{hik} is net benefit of crop *k* in sub-area *h* for soil type *i* (Kip/ha), and $X_{hijk,}$ is irrigated area of crop *k* in sub-area *h* for soil type *i* during season *j* (ha).

The constraints of the model can be divided into two categories including water constraint and land area constraint.

The water constraint considered the irrigation efficiency [12],[13]. The overall water efficiency of the irrigation project, which described as:

$$E_{overall} = \frac{SWR - ER}{WDF} x100 \quad (2)$$

where $E_{overall}$ is overall efficiency of the irrigation project, *SWR* is total scheme waster requirement(m^3), *ER* is effective rainfall (m^3), and *WDF* is water delivery to the paddy fields.

$$SWR = \sum_{u=1}^{U}\int_{v=1}^{V} WR_{vu} x A_{vu} \quad (m^3) \quad (3)$$

$$WDF = (I * E_c + N) - (D + C) \ (m^3) \quad (4)$$

where: *I* is intake water through main canal (m^3), E_c is canal efficiency, *N* is total natural flow entering command area (m^3), *D* is drain water to sink outside without reuse or non-utilizable water supply (m^3), *C* is committed flow to other areas (e.g legally and conventionally committed outflow from command areas to outsides (m^3)), WR_{vu} is crop water requirement (mm/dayx10^{-3}) of crop type *u* at the day *v*, A_{vu} is actual cultivated area (m^2) of crop type *u* at the day *v*.

For Paddy:

$$WR_p = ET_o * K_c + P + LP \quad (5)$$

For Non-paddy Crop:

$$WR_N = ET_o * K_c \quad (6)$$

For Fish pond

$$WR_p = ET_o * K_c + P \quad (7)$$

where ET_o is potential or reference evapo-transpiration in mm/day, K_c is crop coefficient (dimensionless), *P* is percolation in mm/day, and *LP* is land preparation in mm/day.

For practical water requirement for fish ponds are calculated in the same way as water requirement for crops. A fish pond is comparable with an evaporation pan therefore one K_c value should be used throughout the year. It is recommended to use a K_c value of 1.2 for calculating requirement for fish pond [13].

The net crop water requirement is not greater than the total available water of the irrigation scheme multiplying the irrigation efficiency of irrigation project, which described as:

$$\sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K} \sigma_{hijk} X_{hijk} \le E_{overall} Vd_j \quad (8)$$

$$\sigma = WR_{vu} \text{ x Stage of crop development} \quad (9)$$

where σ_{hijk} is crop water requirement rate of crop *k* in sub-area *h* for soil type *i* during season *j* (mm/ha), Vd_j is total available water of the irrigation system during season *j* (Mm^3), and $E_{overall}$ is the overall irrigation efficiency of the irrigation project.

The seasonal available water of each zone (q_{hj}) is calculated by multiplying the net available water of the irrigation system with a proportion of each zone area and total area (T_j), which presented as:

$$q_{hj} = E_{overall} Vd_j \left(\frac{X_{hj}}{T_j} \right) \quad (10)$$

$$\sum_{i=1}^{I}\sum_{k=1}^{k} \sigma_{hijk} X_{hijk} \le q_{hj} \quad (11)$$

For the land constraint, the summation of all zone area is not greater than the available total area of scenario during season *j*; which described as:

$$\sum_{h=1}^{H} X_{hj} \le T_j \quad (12)$$

In each zone divided into several sub-areas suitable to soil type. The total land area of all soil type is not larger than the available area of the zone, which presented as:

$$\sum_{i=1}^{I}\sum_{k=1}^{K} X_{hijk} \le X_{hj}; \quad (13)$$

for h=1,2,3….H

The net irrigated area of all crops is not greater than the land area of each soil type. The irrigated area of each crop is not larger than the suitable area for its cultivation. These constraints are of the following form:

$$\sum_{k=1}^{K} X_{hijk} \le X_{hij}; \quad (14)$$

for *h*= 1,2,3,…H and *i* = 1,2,3…I

$$X_{hijk} \le S_{hijk}; \quad (15)$$

for *h*= 1,2,3,…H and *i* = 1,2,3…I and *k*= 1,…K

$$X_{hijk} \ge 0 \quad (16)$$

where S_{hijk} is amount of suitable land for the cultivation of crop *k* in sub-area *h* for soil type *i* during season *j* .

In order to consider the multi-functioned character of paddy field of the suitable soil type for cultivation each crop, the zone area is divided into several suitable soil types (see figure 1).

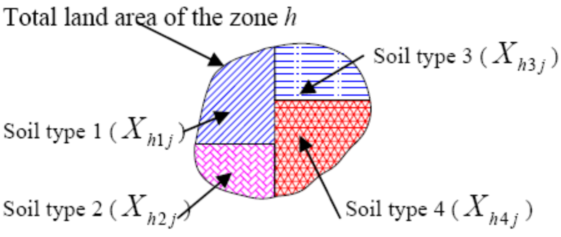

Figure 1. The suitable soil type for the cultivation in a zone area.

3. Illustrative Application

The 26-year (1982-2007) of seasonal flow, irrigated area, irrigation efficiency, crop water requirement, related evaporation and effective rainfall of the Nam Houm Irrigation Scheme during dry season (November- April) were considered for illustrative application of the proposed approach. Figure 2 presents the location of the Nam Houm Irrigation scheme in the Central of Lao PRD.

The Nam Houm Irrigation System (NISO) has an estimated irrigation service area of 4,200 hectares during wet season and 2,400 hectares during the dry season.

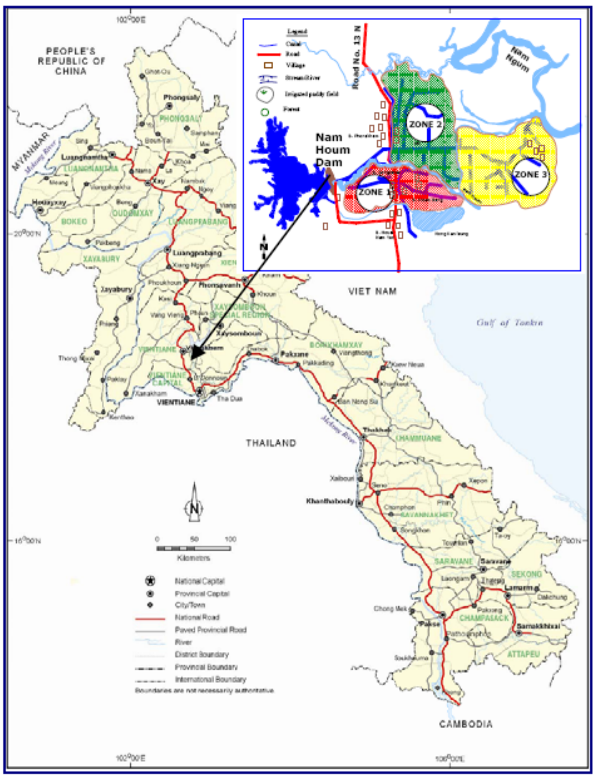

Figure 2. Location Map of Nam Houm Irrigation Scheme

The historical record of irrigated area in Nam Houm from 1989 to 2007, the average irrigated area during the wet season is 1,986 hectares and 1,441.79 during the dry season (rice, non-rice crops and fish ponds). It must be noted that the reported wet season irrigation area does not represent the total area planted during the wet season as the 4,200 hectares most likely are all planted to rice during the wet season and most of these are depending on rain for water supply.

The reservoir has a catchment area of 108 km^2 with annual inflow of 149.5 Mm^3. The maximum storage is 60 Mm^3 (active of 54 Mm^3, and dead of 6 Mm^3.). The estimation of maximum flood level is 190.1 MSL (mean sea level) and crest of dam of 192.2 MSL, spillway at 189.1 MSL and intake at 178.8 MSL. Reservoir was not filled-up to maximum capacity in the past wet season 2006.

For water distribution practices, water balance is considered before every cultivation season. If storage is kept as high as 189.1 MSL (in other words 60 Mm^3) at the end of rainy season, a constant amount of water will be supplied continuously with no limitation. However, a rotation method is applied when water in the reservoir is insufficient. When water level under normal level, cultivated area are estimated according to water storage e.g., in 2003, water level of 186.41 MSL (36 Mm^3) could irrigate only 1,400 ha.

Due to the cultivated areas are limited according to available water. Water delivery is limited to one zone at the same time with regular rotation from zone 1 to zone 3. Some areas are abandoned, especially the areas which are located far away from the canals. The overall irrigation efficiency of the Nam Houm Irrigation Scheme is 70.52 % [13].

The proposed LP model is applied to find an optimum crop pattern of the Nam Houm Irrigation Scheme subject to restriction on water availability and land area. There are four land use types (rice, cucumber, maize and fish pond) in the considered project. However, fish ponds are not included to allocate because they are fixed always. The total area of scenario for several years cultivation is 2,400 ha (1 ha = 10,000m^2) that is divided in to 3 zones, including zone No. 1 of 550 ha, zone No. 2 of 900 ha and zone No. 3 of 950 ha.

Table 1. Crop water requirement rate of each crop for seasonal cultivation [13], [14]

Cultiva-tion crops	Crop Water Reqt. (m^3/ha)	Yield (kg/ ha)	Crop price (Kip/kg)	Benefit (Kip/ ha)
rice	12,945.8	3,284	3,000~ 4,000	3,110, 888
Cucum-ber	4,781.7	8,688	1,500~ 2,000	3,080, 150
maize	4,604.6	5,518	1,000~ 2,000	1,113, 200
fish pond	8,840.7	2,070	10,000~ 15,000	6,512, 000

In this paper, the efficiency of the proposed LP model that can take into account of multi-functioned paddy fields is presented. For this reason, the mono-functioned character of the irrigation project is considered for comparing the case study.

These amounts of available water, 10, 20, 30, 40, and 54 Mm^3 were applied to the proposed model for finding optimal crop pattern. Figure 3 shows the optimum crop pattern of the proposed and existing LP models (Mono-functioned character) for the available water of 20 Mm^3. The crop patterns of the proposed LP model are appropriately for the targeted irrigation areas of the project for all provide water. For crop patterns of existing LP model are unsuitable for the targeted irrigation areas, because the obtained patterns are larger and used more water than the proposed LP model.

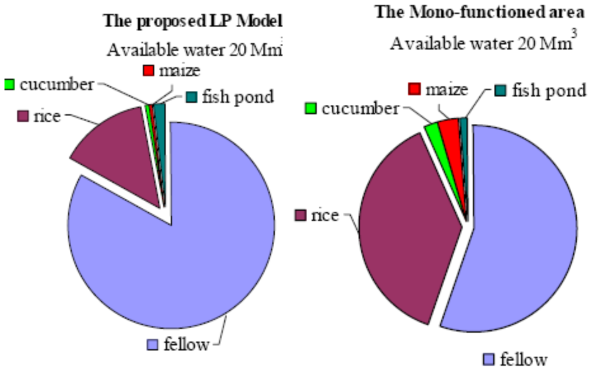

Figure 3. Optimal crop pattern of the proposed and mono-functioned area.

Table 2 shows the net benefit of the scenario using the proposed LP model (multi-functioned characters of project) and the existing model (mono-functioned characters of project). The request area of 2,400 ha and available inflow from 10 to 54 Mm^3 respectively, were used to test the efficiency of the proposed model. The results show that the proposed model provided net benefit higher than the existing model for all cases. In addition, the sum of net benefit for multi-functioned case (3,274.16 Million Kip) is larger than the sum of net benefit for mono-functioned case (2,158.80 Million Kip). It indicates that variation of multi-functioned has a large impact on the optimal solution. For this reason, LP model with multi-functioned character of land area is appropriately for finding optimum crop pattern.

Table 2. Net benefit of the scenario using the Multi-functioned area (proposed model) and the Mono-functioned area

Request area (ha)	Available water (Mm^3)	Total benefit (Million Kip)	
		Multi-functioned	Mono-functioned
2,400	10	186.60	209.60
	20	395.58	243.40
	30	529.29	345.30
	40	702.23	453.50
	50	730.23	453.50
	54	730.23	453.50
Sum		3,274.16	2,158.80

4. Conclusion

This paper used a LP model by considering multi-functioned soil type on paddy fields to allocate the available land area under limited water supply. The irrigation project was divided into several sub-area based on suitable soil type for each crops for representing the multi-functioned characters of the large scenario in term of crop water requirement and crop yield. There are two main constraints of the proposed model, including water constraint and land area constraint. The proposed LP model provided the optimum crop pattern with net seasonal benefit which corresponding seasonal available water and required cultivation area.

Maximum net benefit comparison is done by taking the highest net benefit of the proposed LP model and highest net benefit of the existing LP model. It is found that the LP model obtained higher net benefit than the existing LP model considering mono-functioned character. The proposed LP model is appropriated to use for planning in the irrigation project.

Acknowledgments

The authors would like to express their appreciation to the Faculty of Engineering, Mahasarakham University for financial support, MRCS and DOI for supporting data.

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The 2rd seminar in title of "Engineering and Architecture for the Sustainable Development in the Mekong Sub-Region" and sport competition,
March 27-31,2008.
Souphanouvong University, Lao P.D.R.

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A MATHEMATICAL MODEL FOR ESTIMATING VARIED IRRIGATION EFFICIENCY

ABSTRACT

This study proposed a mathematic model for estimating of irrigation efficiency. The proposed model was considered the previous situation, current situation and introduces up-to-date concept in assessing irrigation efficiencies to manage water resources more efficiently, sustainably and productively. The proposed model not only to determine of overall irrigation efficiency, but covers all aspects improvement factors such as capacity of stakeholders, product costs etc. The approach model was applied to determine of irrigation efficiency of Nam Houm Irrigation Scheme, (in the Central region of Lao PDR). The results obtained that the mathematic models can be used for estimating of varied irrigation efficiencies, given the total available water resources, farmer participation and requested irrigation-area. The model provided the optimal condition of the irrigation efficiencies which are close to the actual irrigation efficiency.

KEYWORDS : Mathematical models, varied irrigation efficiency, farmer participation, water resources management.

1. INTRODUCTION

Irrigation Efficiency is an obvious issue for agricultural development. Improvement irrigation efficiency not only can improve equity in water distribution but also can minimize the gab between crop water requirements and actual water use. In consequence, it will lead to determine the effectiveness of water use and lead to improve the livelihood people. Generally, irrigation efficiency is the overall system efficiency which affecting by conveyance, distribution and paddy field application. Most previous studies mainly analyzed field level efficiencies, and considered the irrigation efficiency as a constant value for all season[1],[2]. However, there are not enough reliable to estimate irrigation efficiencies and actual water use.

However, it is likely that the efficiencies tend to vary due to the uncertainty of water resources. The participation of stakeholder in water resources management is main effect of irrigation efficiencies [3]. Hence, participation of stakeholder in water resources management is important factor for estimating irrigation efficiency.

A multiple regression is the mathematical relationship which describes a system by a set of variables and a set of equations that establish relationships between the variables. The values of the variables can be practically anything such as mathematical relationships between the advance time and distance from the stream end using regression function for analysis [4]. The multiple regressions can be useful tool to determine the irrigation timing as a function of environmental and operational conditions (e.g. working pressure, air temperature, relative humidity, etc.) in order to minimize evaporation and drift loss [5]. A mathematical model is search and optimization techniques based on linear and non-linear multiple equations. The mathematical model is a method for searching the memberships of functions and it was applied to solve the optimal solution of water resources and varied irrigation efficiencies problems [6]. In addition, this mathematical model is relatively easy to explain and understand.

This study thus proposes the mathematical model for finding the varied efficiency which corresponding seasonal inflow, farmer participation in water resources management, land area cultivation in the previous season and cost of crop production. The relationship between input and output variables is defined from a mathematical formula, according to human processes in thinking and decision

2. MODEL FORMULATION

Multiple regression (or, more generally, "regression") allows researchers to examine the effect of many different factors on some outcome at the same time. The general purpose of multiple regressions is to describe about the relationship between several independent or predictor variables and a dependent variable. For some kinds of research questions, regression can be used to examine how much a particular set of predictors explains differences in some outcome.

Thus, multiple regressions are usually composed by variables, which are abstractions of quantities of interest in the described systems, and operators that act on these variables, which can be algebraic operators, functions, differential operators, etc. If all the operators in a mathematical model present linearity, the resulting mathematical model is defined as linear. A model is considered to be nonlinear otherwise.

In order to account for any uncertainty on seasonal inflow, land area of cultivation, product cost and farmer participation in water resources management, the mathematical model by using linear and non-linear multiple equations for estimating varied irrigation efficiency. System inputs include the seasonal inflow, seasonal requested area, participation of stakeholders and product cost. Output is the seasonal irrigation efficiency from various seasonal operation factors.

There are three steps in developing mathematical model as the following:

The first step of creating a mathematical model is to test the variables input. If all variables in the mathematical model present linearity, the resulting mathematical model is defined as linear and if otherwise will be considered as non-linear. The mathematical formula for estimating variables is:

$$y_{ij} = a * X_1^{b_1} * X_2^{b_2} * X_3^{b_3} * ..... * X_m^{b_m} \qquad (1)$$

where y_{ij} is estimated irrigation efficiency of scenario i during the season j; a and b_i are parameters of multiple functions during the scenario i $(i=1,2,3...m)$; X_1 is seasonal variable of total irrigated areas; X_2 is seasonal variables of farmer participation in water resources management; X_3 is seasonal variable of inflow; X_4 is seasonal product cost; and X_m is seasonal variables input for estimating parameters of the mathematical model of scenario m.

The secondly, the parameters of multiple functions were used to estimate irrigation efficiencies on each historical data. The actual historical data of irrigation efficiency will be presented in the next section.

Finally, the mathematical model was evaluated by considering the coefficient of correlation (r) and coefficient of determination (R^2) which define base on the actual irrigation efficiency and estimated irrigation efficiency from the model as:

$$R^2 = \frac{\left(\sum_{j=1}^{n} e_j \hat{e}_j - n\bar{e}_j \bar{\hat{e}}_j\right)^2}{\left(\sum_{j=1}^{n} e_j^2 - n\bar{e}_j^2\right)\left(\sum_{j=1}^{n} \hat{e}_j^2 - n\bar{\hat{e}}_j^2\right)} \qquad (2)$$

where e_j is the estimated irrigation efficiency of the scenario during season j which calculated using mathematical model, $\hat{e}_j$ is the actual irrigation efficiency of the scenario during season j which calculated from irrigated area, participation of stakeholder, product cost and value of available water,

$\bar{e}$ and $\bar{\hat{e}}$ are respectively the average of above mentions and n is the number of annual historic data.

Generally, irrigation efficiency is the overall system efficiency which affecting by conveyance, delivery and field application efficiencies [7],[8]. The actual irrigation efficiency of the system can be computed by following equation:

$$\hat{e}_j = 100\left(\frac{V_{net}}{V_{gross}}\right) \quad (3)$$

where: V_{net} is the net volume of crop water requirement (m^3), V_{gross} is the gross water diverted from the source to the conveyance system (m^3).

The net volume of crop water requirement is computed as:

$$V_{net} = \sum_{j=1}^{j}\sum_{k=1}^{K} CWR_{jk} X_{jk} \quad (4)$$

$$CWR = WR_{vu} \text{ x Stage of crop development} \quad (5)$$

where: CWR_{jk} is crop water requirement rate of crop k during season j (mm/ha), X_{jk} is cropped area of crop k during season j(ha), WR_{vu} is crop water requirement (mm/dayx10^{-3}) of crop type u at the day v.

3. ILUSTRATIVE APPLICATION

The 18-year (1989-2007) of seasonal flow, irrigated area, irrigation efficiency, crop water requirement, related evaporation and effective rainfall of the Nam Houm

Irrigation Scheme during dry season (November-April) was considered for illustrative application of the proposed approach. Figure 1 presents the location of the Nam Houm Irrigation scheme in the Central of Lao PDR.

The Nam Houm Irrigation System (NISO) has an estimated irrigation service area of 4,200 hectares during wet season and 2,400 hectares during the dry season.

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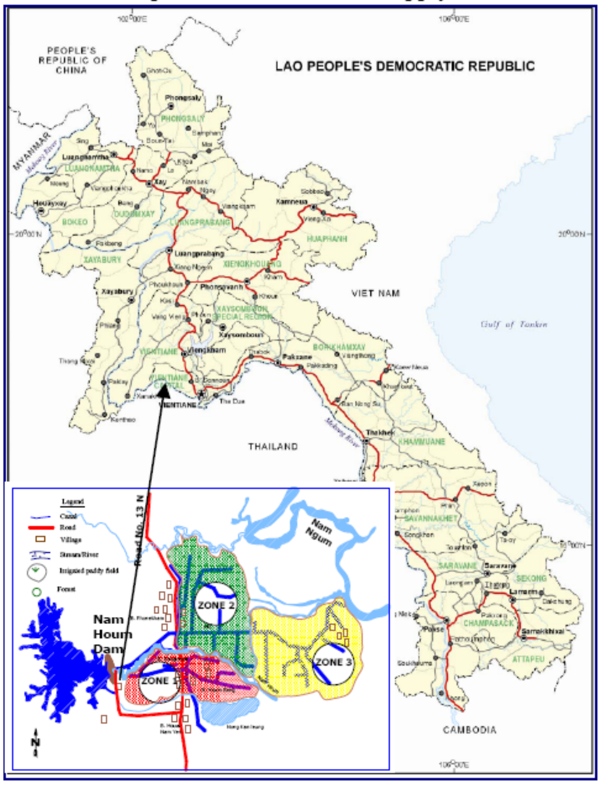

Figure 1 Location Map of Nam Houm Irrigation Scheme

The reservoir has a catchments area of 108 km^2 with annual inflow of 149.5 Mm^3. The maximum storage is 60 Mm^3 (active of 54 Mm^3, and dead of 6 Mm^3.). The estimation of maximum flood level is 190.1 MSL (mean sea level) and crest of dam of 192.2 MSL, spillway at 189.1 MSL and intake at 178.8 MSL. Reservoir was not filled-up to maximum capacity in the past wet season 2006.

For water distribution practices, water balance is considered before every cultivation season. If the storage kept as high as 189.1 MSL (in other words 60 Mm^3) at the end of rainy season, a constant amount of water will be supplied continuously with no limitation. However, a rotation method is applied when water in the reservoir is insufficient. When available water level under normal level, cultivated area are estimated according to water storage e.g., in 2003, water level of 186.41 MSL (36 Mm^3) could irrigate only 1,500 ha.

Due to the cultivated areas are limited according to available water. Water delivery is limited to one zone at the same time with regular rotation from zone 1 to zone

3. Some areas are abandoned, especially the areas which are located far away from the canals. The overall irrigation efficiency of the Nam Houm Irrigation Scheme is 70.52 % in 2006 [2].

Table 1 Historical data of requested irrigation-area, participation of stakeholder in water resources management, available inflow, cost of product and actual irrigation efficiency.

Year	Total Area last yrs	Farmer Partici-pation	Inflow	Unit Cost Rice	Actual irrigation efficiency
	(ha)	(%)	($x10^6$ m^3)	(Kip/ kg)	(%)
1989	473.16	20.55	7.83	180	79.27
1990	493.16	23.55	8.61	212	82.76
1991	565.20	29.72	11.49	230	79.19
1992	713.20	26.50	10.08	255	79.22
1993	635.90	22.27	8.37	283	79.26
1994	534.50	29.80	11.16	334	78.83
1995	715.26	41.60	15.70	633	78.37
1996	998.51	45.10	16.86	803	77.98
1997	1,082.35	53.04	22.16	1,305	77.45
1998	1,405.35	54.33	22.60	1,708	77.87
1999	1,440.70	60.00	25.09	1,871	77.33
2000	1,581.81	91.67	38.33	2,000	76.77
2001	2,376.05	99.63	40.78	2,200	77.05
2002	2,467.05	102.38	42.10	2,648	78.34
2003	2,672.17	58.33	30.60	2,919	62.44
2004	1,575.17	100.00	46.30	2,897	69.85
2005	2,635.17	100.00	45.30	3,750	71.56
2006	2,643.96	68.75	31.64	4,069	70.45
2007	2,644.96	69.55	34.64	4,070	70.40

4. RESULTS AND DISCUSSION

Table 2 shows the parameters of multiple regression functions. The results shown that the parameters of determination of multiple regressions functions were provided the optimal condition for calibration the varied efficiencies.

The mathematical model was evaluated by considering the coefficient of correlation (r) and coefficient of determination (R^2) which defined based on the actual irrigation efficiency and the estimated irrigation efficiency of all variables input as shown on table 3.

Table 2 Parameters of multiple regression function for estimating irrigation efficiency.

Variables input	Multiple coeffi-cient	Total Area (X_1)	Farmer Partici-pation (X_2)	Inflow (X_3)	Unit Cost Rice (X_4)
	a	b_1	b_2	b_3	b_4
X_1-X_2	4.962	-0.129	0.071		
X_1-X_3	4.720	-0.107		0.037	
X_1-X_4	4.801	-0.057			-0.010
X_2-X_3	8.696		0.768	-0.742	
X_3-X_4	4.196			0.071	-0.079
X_4-X_2	4.529		-0.093		0.115
X_1-X_2-X_3	8.733	0.033	0.774	-0.750	
X_1-X_2-X_4	4.711	-0.055	0.114		-0.063
X_1-X_3-X_4	4.351	-0.061		0.074	-0.047
X_2-X_3-X_4	8.847		0.786	-0.769	0.006
X_1-X_2-X_3-X_4	8.842	-0.003	0.783	-0.766	0.007

The coefficient of correlation (r) of relationship between irrigated area, participation of stakeholder in water resources management, available inflow and product cost (X_1-X_2-X_3-X_4) highest values is 0.940 of all variables input and also the coefficient of determination (R^2) of all variables is highest values of 88.3% respectively. Therefore, these variables input with X_1-X_2-X_3-X_4 is suitable for estimating irrigation efficiency given the optimal condition of calibration. The least value of coefficient of correlation (r) is 0.729 of total irrigated area and inflow relationship(X_1-X_4). and also the coefficients of determination is 52.3%.

The Power regression equation of mathematical model for relationship between irrigated area, participation of stakeholder in water resources management, available inflow and product cost (X_1-X_2-X_3-X_4) is nearing non-linearity if comparison between others relationships with the values of exponent of (Xi) and the coefficients of determination (R^2) which it showed in table 2, the multiple regression function as follow:

$$y = 6918.816 * X_1^{-0.003} * X_2^{0.783} * X_3^{-0.766} * X_4^{0.007} \quad (6)$$

Table 3 The coefficient of correlation (r) and coefficient of determination (R^2)

Variables input	Average of Actual irrigation efficiency (%)	Average of Estimated efficiency from model (%)	Coeff. of correlation r	Coeff. of determination R^2 (%)
X_1-X_2	76.02	75.62	0.759	57.6
X_1-X_3	76.02	75.89	0.729	53.2
X_1-X_4	76.02	75.78	0.723	52.3
X_2-X_3	76.02	75.91	0.939	88.1
X_3-X_4	76.02	75.65	0.733	53.8
X_4-X_2	76.02	143.81	0.784	61.4
X_1-X_2-X_3	76.02	76.08	0.939	88.2
X_1-X_2-X_4	76.02	75.95	0.798	63.7
X_1-X_3-X_4	76.02	75.78	0.748	56.0
X_2-X_3-X_4	76.02	75.52	0.939	88.2
X_1-X_2-X_3-X_4	76.02	75.42	0.940	88.3

Figure 2 shows the relationship between actual irrigation efficiency and estimated irrigation efficiency for all variables input with highest value of coefficient of correlation, (r). The graph shown, that the estimated irrigation efficiency from the model was very closed to the actual irrigation efficiency for all variables of multiple regression function, with consideration of the irrigated area, participation of stakeholder in water resources management, seasonal inflow and product cost.

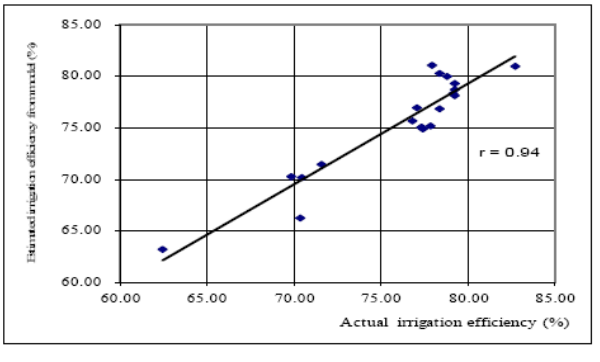

Fig. 2 Actual irrigation efficiency and estimate irrigation efficiency from mathematical model relationship for inputting variables of requested irrigation-area, participation of stakeholder in water resources management, value of available inflow, and cost of product.

Table 4 Deviation between the estimated irrigation efficiency and the actual efficiency which calculated from irrigated area, participation of stakeholder, product cost and value of available inflow.

Year	Actual irrigation efficiency (%) $\hat{e}_j$	Estimated irrigation efficiency (%) e_j	Deviation $\left\|\hat{e}_j - e_j\right\|$
1989	79.27	78.12	1.15
1990	82.76	80.94	1.82
1991	79.19	78.37	0.83
1992	79.22	78.71	0.51
1993	79.26	79.32	0.06
1994	78.83	80.02	1.19
1995	78.37	80.31	1.95
1996	77.98	81.07	3.09
1997	77.45	74.89	2.56
1998	77.87	75.24	2.63
1999	77.33	75.10	2.23
2000	76.77	75.67	1.10
2001	77.05	76.99	0.07
2002	78.34	76.84	1.49
2003	62.44	63.20	0.76
2004	69.85	70.29	0.44
2005	71.56	71.49	0.07
2006	70.45	70.21	0.24
2007	70.40	66.25	4.15

Table 4 shows the deviation between the estimated irrigation efficiency and the actual efficiency which calculated from irrigated area, participation of stakeholder, product cost and value of available inflow. The results shown that the estimated irrigation efficiencies are closed to the actual irrigation efficiencies all series. Except in 2007, the deviation is quite high with number of 4.15. It indicates that the varied irrigation efficiency by using mathematical model is more precise. Consequently, the parameters of multiple regression function with all variables input (X_1-X_2-X_3-X_4) of the illustrative model is appropriately to find the varied irrigation efficiency for irrigation planning.

5. CONCLUSION

This paper is developed a mathematical model for finding the varied irrigation efficiency. The improvement process used the multiple regression technique to search the optimal condition of parameters of multiple regression functions. The developed model was applied to determine the irrigation efficiency of the Nam Houm Irrigation Scheme (in the Central of Laos). The theory of mathematical functions which applied in this study can be used to estimate irrigation efficiencies, when the previous irrigated area, participation of stakeholder in water resources management, available inflow, and product cost are given.

The results also shown that the estimated irrigation efficiencies are closed to the actual irrigation efficiencies all series of variables input. It indicates that the varied irrigation efficiency using mathematical model is more precise. Consequently, the parameters of multiple regression function with all variables input of the model is appropriately to find the varied irrigation efficiency for irrigation planning.

This paper is developed a mathematical model for finding the varied irrigation efficiency. The improvement process used the multiple regression technique to search the optimal condition of parameters of multiple regression functions. The developed model was applied to determine the irrigation efficiency of the Nam Houm Irrigation Scheme (in the Central of Laos). The theory of mathematical functions which applied in this study can be used to estimate irrigation efficiencies, when the previous irrigated area, participation of stakeholder in water resources management, available inflow, and product cost are given.

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6. ACKNOWLEDGMENTS

The authors would like to express their appreciation to the Faculty of Engineering, National University of Laos for financial support, MRCS and DOI for supporting data.

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An Allocation LP Model for Planning Dry-Season Irrigation Project

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Abstract

Crop pattern is important information for farmer that used to be the guidelines in the beginning of seasonal cultivation. This paper proposes an allocation LP model that can take into account heterogeneity of water requirement and crop yield of irrigation area for finding optimal crop pattern. A sensitivity analysis of irrigation efficiency in the LP model was accounted in the study. The proposed model was applied to find the dry-season (Mid December – Mid April) crop pattern of the Huai-Ang Irrigation Project located in the Northeast Region of Thailand. The records of seasonal flow, requested and actual irrigation areas, crop water requirement, crop yield, evaporation, and effective rainfall of the project were used for this illustrative application. Results showed that the proposed LP model is feasible for finding the optimal crop pattern. Heterogeneous character in allocation LP model provided the crop pattern that suitable for cultivating crop on the actual land area. The consideration of vary irrigation efficiency in irrigation planning provided the optimal crop pattern that can be given the higher gross benefit.

Keywords: optimization model, linear programming, irrigation planning, dry-season crop pattern, varied irrigation efficiency

1. Introduction

Irrigation planning under limited available resources (such as water, irrigated area, production cost and man power etc.) is the one of the classical problems in water resource management. Crop pattern of the irrigation project is the land-area that provided for cultivating each crops. Therefore, the farmer needs to have the optimum cropping pattern which will maximize the economic return.

A linear programming (LP) is an optimization technique which widely used to allocate the limited resources because of the proportionate characteristic of the allocation problem [1,2]. One popular application of the technique in the water resource literatures is to find an optimal seasonal crop pattern which subjected to limited available resources [3,4,5]. Often, the maximization benefit was set as the objective function based on the resource constraints. The objective function and constraint functions are formulated as linear equation for finding optimum crop pattern. The portion of treated water from waste water treatment and ground water are included into the water constraints of the LP model [6,7]. Moreover, water quality parameters (salinity and suspended solid) are incorporated into the LP model [8]. Also, a pricing of irrigation water is considered in the constraints of LP model [9].

Often, most previous studies assumed a homogeneity in crop water requirement and crop yield for all land area of the considering project. The obtained crop yield is usually affected by sufficient crop water requirement and physical soil type which suitable for cultivation of each crop [10,11]. In addition, most previous studies considered irrigation efficiency as a constant value in calculating available water. Generally, irrigation efficiency is a vary value based on amount of available water and farmer participation in water resource management [12,13].

The purpose of this paper is to propose an allocation LP model that can take into account heterogeneity of land area in term of crop water requirement and crop yield. A sensitivity of irrigation efficiency is presented in this study.

2. Formulation Model

The linear programming is used to be a based model for finding optimal seasonal crop pattern. The model will be formulated to maximize benefit subjected to the limited resources on available dry-season water and crop water requirement, crop yield and net benefit of each crop. The obtained crop pattern can be used for dry-season planning which considering the heterogeneous character of the irrigation project. The objective function of the model can be presented as:

$$Max\ Z_j = \sum_{h=1}^{H}\sum_{k=1}^{K}\left(Y_{hk}P_{hk} - C_{hk}\right)X_{hjk} \qquad (1)$$

where Z_j is the gross benefit of the irrigation project during the dry-season j; h is sub-area index (based on main canal) of the irrigation project (h = 1, 2, 3,...,H); k is crop type (k = 1, 2, 3,…,K); Y_{hik} is crop yield of crop k in sub-area h (kg/ha); P_{hik} is crop price of crop k (baht/kg); C_{hik} is production cost of crop k in (baht/ha); and X_{hjk} is irrigated area of crop k in sub-area h (ha).

The constraints of the model can be divided into two categories including amount of water constraint and land area constraint. The amount of water constraint considered both constant value and varied value of irrigation efficiency [14]. The net crop water requirement is not greater than the total available water of the irrigation system multiplying the irrigation efficiency of the irrigation project, which described as:

$$\sum_{h=1}^{H}\sum_{k=1}^{K}\sigma_{hjk}X_{hjk} \le \phi Vd_j \qquad (2)$$

where σ_{hjk} is crop water requirement rate of crop k in sub-area h during season j (mm/ha); Vd_j is total available water of the irrigation system during season j (MCM); and ϕ is the irrigation efficiency of the irrigation project. The seasonal available water of each Canal Zone (q_{hj}) is calculated by multiplying the net available water of the irrigation system with a proportion of each main canal zone and total area of the project (T_j), which presented as:

$$q_{hj} = \phi Vd_j\left(\frac{X_{hj}}{T_j}\right) \qquad (3)$$

$$\sum_{k}^{K}\sigma_{hjk}X_{hjk} \le q_{hj} \qquad (4)$$

For the land area constraint, the summation area of all main canal zone is not greater than the available total area of irrigation project during season j, which described as:

$$\sum_{h=1}^{H}X_{hj} \le T_j \qquad (5)$$

The net irrigated area of all crops is not greater than the land area of each main Canal Zone. The irrigated area of each crop is not larger than the suitable area for its cultivation. These constraints are of the following form:

$$\sum_{k=1}^{K}X_{hjk} \le X_{hj};\ \text{for } h = 1,\ldots,H \qquad (6)$$

$$X_{hjk} \ge 0 \qquad (8)$$

3. Results and Discussions

The 21-year (1988 - 2008) of seasonal flow, irrigated area, crop water-requirement, crop yield, related evaporation and effective rainfall of the Huai Ang Irrigation Project during dry season (Mid December – Mid April) were considered for illustrating the application of the proposed approach [14]. Figure 1 presents the location of the Huai Ang Irrigation Project in the Northeast region of Thailand.

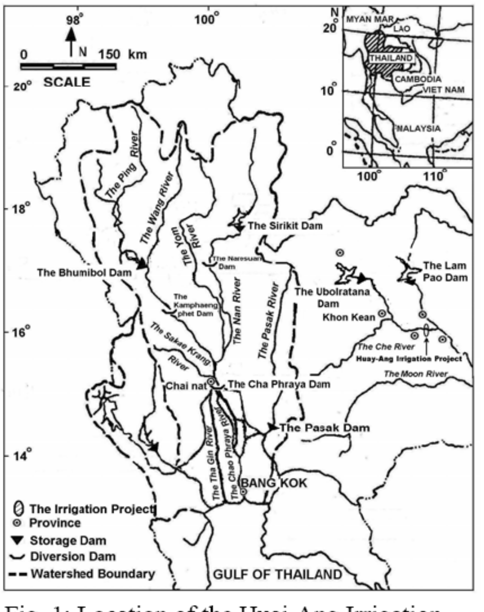

Fig. 1: Location of the Huai Ang Irrigation Project

The developed LP model is applied to find an optimum crop pattern of the Huai Ang Irrigation Project subject to restriction on available water and land area. There are four land use types (corn, water melon, vegetable and rice) in the considered project during dry-season. The other crops that irrigated area below to 1 ha (1 ha = 10,000 m^2) are not incorporated. The fish farms are not included to allocate because they are fixed always. The total area of scenario during dry-season is 7,200 ha

Table 1 shows calculated values of crop water requirement rate, crop yield and crop benefit, when the irrigation project was considered as homogeneous character and heterogeneous character. It indicates that crop yields of all crops in considered scenario as homogeneous character are smaller than their heterogeneous. Moreover, the crop water requirement rates of the homogeneous consideration are less than the heterogeneous one. For this reason, the benefits per hectare of the homogeneous consideration for all crops are small as compare with those of suitable soil type for heterogeneous consideration. These crop water requirement rate, yield and benefit in table 1 will be used in the existing LP model for finding optimal crop pattern.

To test the effectiveness of the approach model in the homogeneity of the irrigation system, a sensitivity analysis was conducted. The analysis tested a variation of the benefit for the considered scenario by changing the homogeneity character under the same resources the results are presented as the following.

Table 2 shows the gross benefit of the scenario using the proposed LP model with heterogeneous (HE) and homogeneous (HO) characters of project. The results show that the model with heterogeneous character of project provided gross benefit higher than the model with homogeneous characters of project for all cases. In addition the obtained patterns of considering heterogeneous are corresponding to the available land areas of the suitable main Canal Zone, while the obtained patterns of homogeneous consideration that having only corn area are not suitable for the availability of land areas.

Table 1: Calculated crop water-requirement rate, crop yield and crop benefit of heterogeneous and homogeneous characters

Crops	Crop water requirement		Crop yield		Benefit	
	HET (mm./ha)	HO (mm./ha)	HET (kg/ha)	HO (kg/ha)	HET (baht/ha)	HO (baht/ha)
corn	6,156	5,479	3,625	2,175	45,000	23,250
watermelon	5,963	5,307	15,625	9,375	34,375	15,625
vegetable	5,888	5,240	750	450	39,375	19,875
rice	15,000	13,350	6,375	3,825	20,500	7,750

Note: HET = Heterogeneous, HO = Homogeneous, 1 US $ ~ 35 Baht

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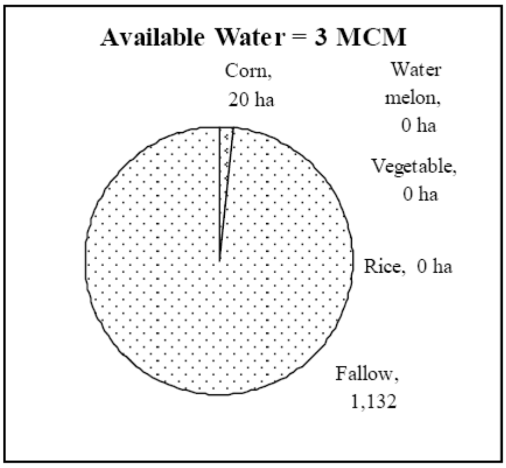
Table 2: Gross benefit of the irrigation project using the proposed LP model with heterogeneous (HE) and homogeneous characters (HO)

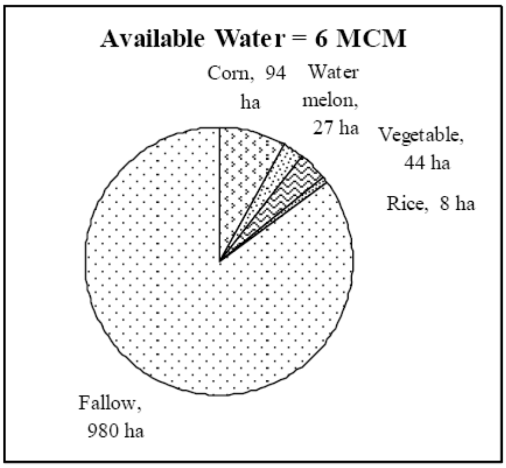
Irrigated Area (ha)	Available Water (MCM)									
	3		6		9		12		15	
	HET	HO	HE	HO	HE	HO	HE	HO	HE	HO
Corn	20.42	22.67	93.95	201.25	156.03	379.83	218.10	558.41	280.17	736.99
Water melon	-	-	26.72	-	26.72	-	26.72	-	26.72	-
Vegetable	-	-	43.52	-	43.52	-	43.52	-	43.52	-
Rice	-	-	8.12	-	48.64	-	89.16	-	129.69	-
Net Benefit (Million Baht)	0.92	0.57	7.03	5.10	10.65	9.63	14.27	14.16	17.90	18.69

Note: HET = Heterogeneous, HO = Homogeneous, 1 US $ ~ 35 Baht

Figure 2 (a, b, c, d, e) shows the optimal crop pattern of the proposed LP models for the available water of 3, 6, 9, 12 and 15 MCM (1 MCM = 10^6 m^3). The crop patterns of the proposed LP model are approximately the targeted irrigation area of the project when having high available water.



(a)



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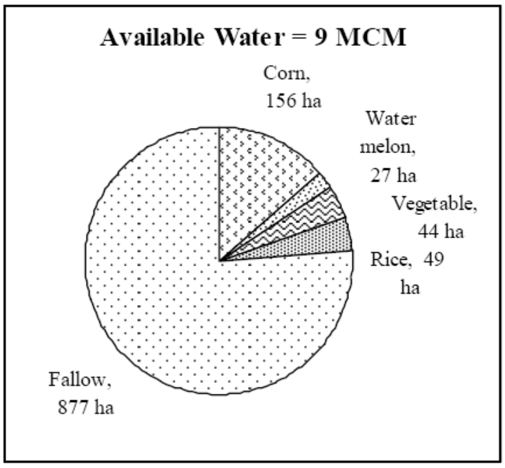

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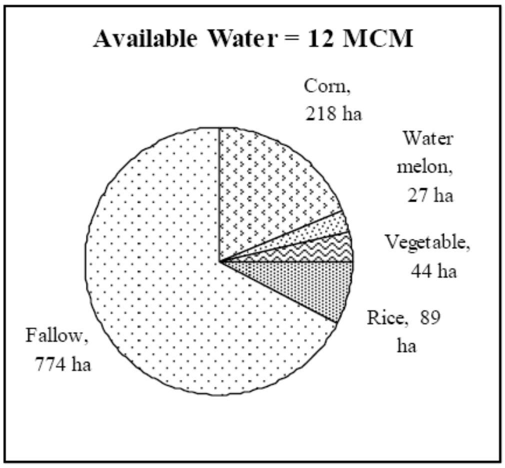

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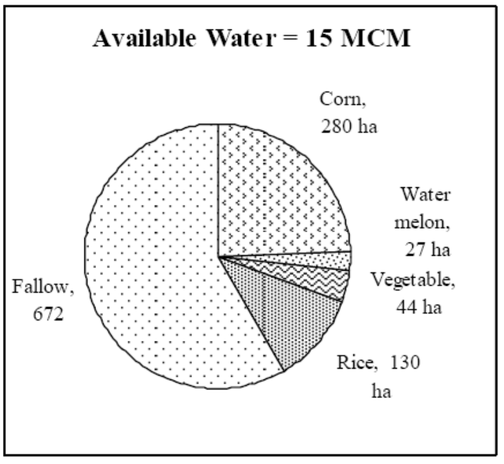

(e)

Figure 2: Optimal crop pattern of the proposed LP model

Table 3 and Figure 3 show the net benefit of the scenario using the proposed LP-based model (heterogeneous character of project) and the existing LP model (homogeneous characters of project). The varied irrigation efficiency of 0.4, 0.5, 0.6, 0.7 and 0.8, and available release water from reservoir of 3 MCM (1 MCM = 10^6 m^3), 6 MCM, 9 MCM, 12 MCM and 15 MCM were used to test the efficiency of the proposed model. The results show that the proposed model with varied irrigation efficiency (V-HE) provides higher net benefit than the model of constant irrigation efficiency (C-HE) for all cases. In addition, the increasing of release water to project gives the higher net benefit following. It indicates that the variation of heterogeneous character has a large impact on the optimal solution. For this reason, LP model with heterogeneous character of land area is appropriate for finding optimum crop pattern.

Table 3: Gross benefit of crop pattern using the developed LP model with heterogeneous and homogeneous characters of project

Irrigation Efficiency	Release (MCM)	Benefit (Million Baht)	
		V-HE	C-HE
0.4	3	2.42	0.92
	6	8.56	7.03
	9	12.96	10.65
	12	17.35	14.27
	15	21.68	17.90
0.5	3	4.50	0.92
	6	10.76	7.03
	9	16.25	10.65
	12	21.68	14.27
	15	26.62	17.90
0.6	3	6.37	0.92
	6	12.96	7.03
	9	19.55	10.65
	12	25.69	14.27
	15	31.09	17.90
0.7	3	7.47	0.92
	6	15.15	7.03
	9	22.72	10.65
	12	29.38	14.27
	15	33.28	17.90
0.8	3	8.56	0.92
	6	17.35	7.03
	9	25.69	10.65
	12	32.05	14.27
	15	35.33	17.90

Note: V-HE = vary irrigation efficiency, C-HE = constant irrigation efficiency that is 0.42 %

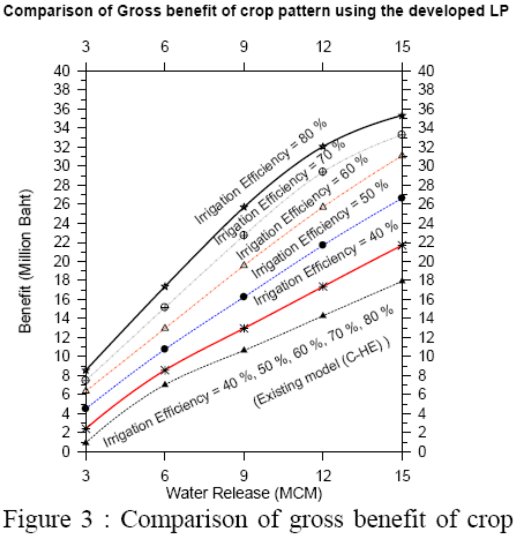

Figure 3 : Comparison of gross benefit of crop pattern using the developed LP with heterogeneous (V-HE) and the existing model (C-HE).

4. Conclusion

This paper proposed a LP model considering heterogeneous of crop water requirement and crop yield for allocating the available land area. A sensitivity analysis of irrigation efficiency and seasonal release in the LP model was conducted in the study. The proposed LP model gave the optimum crop pattern with gross dry-season benefit that corresponding seasonal available water and suitable for actual irrigated area. It provided the higher benefit as compare to the LP model considering homogeneous character. The obtained patterns of considering heterogeneous are corresponding to the available land areas of the suitable main canal zone. Heterogeneous character of scenario in term of crop water requirement and crop yield in the LP model has affected to the cropping patterns. The vary irrigation efficiency that used in irrigation planning provided the optimal crop pattern that can be given the higher gross benefit.

5. Acknowledgement

The authors would like to express their appreciation to the staff of Huai Ang irrigation project for supporting data.

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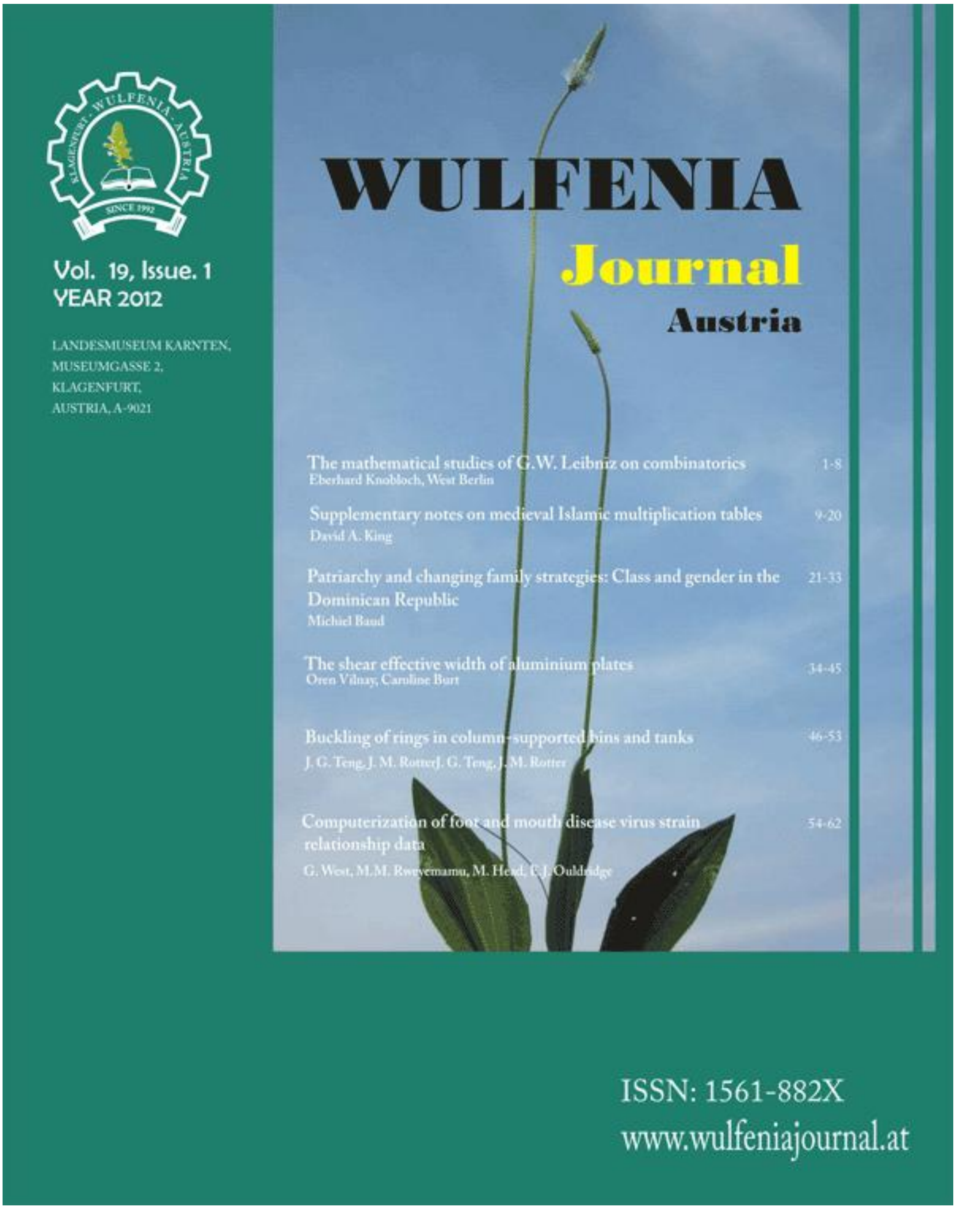
Appendix D
Academic Journals



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SINCE 1992
Vol. 19, Issue. 1
YEAR 2012
LANDESMUSEUM KARNTEN,
MUSEUMGASSE 2,
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WULFENIA
Journal
Austria
The mathematical studies of G.W. Leibniz on combinatorics 1-8
Eberhard Knobloch, West Berlin
Supplementary notes on medieval Islamic multiplication tables 9-20
David A. King
Patriarchy and changing family strategies: Class and gender in the Dominican Republic 21-33
Michiel Baud
The shear effective width of aluminium plates 34-45
Oren Vilnay, Caroline Burt
Buckling of rings in column-supported bins and tanks 46-53
J. G. Teng, J. M. RotterJ. G. Teng, J. M. Rotter
Computerization of foot and mouth disease virus strain relationship data 54-62
G. West, M.M. Rweyemamu, M. Head, C.J. Ouldridge
ISSN: 1561-882X
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JOURNAL
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home about us contact Frequency aims and scopes announcements

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No.8, volume 19, Aug 2012

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Stakeholders involved in water resources management project in Laos PDR

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ENTREPRENEURIAL ORIENTATION AND THE ORGANIZATIONAL PERFORMANCE: EXPLORING THE MEDIATING ROLE OF ENTREPRENEURIAL CULTURE USING PARTIAL LEAST SQUARES APPROACH

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Vol 19, No. 8;Aug 2012

Stakeholders involved in water resources management project in Laos PDR

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Abstract

This study proposes a water resources linking issue of system infrastructures, environmental change, water allocation, assessment of water requirement, flow measurement and responsibility of stakeholders. The study presents the field activities in the pilot project of Nam Houm Irrigation Scheme, Laos PDR to update information by undertaking field observation, interviewing stakeholder and collecting data. It is found from the results that water requirement is appraised using all parameters conducted in the fields. Those parameters are described as follows; evaporation, ETo, rainfall, crop coefficient, evapotranspiration, percolation, identify actual planted area, cropping pattern and crop calendar. The project water management appraisal was conducted including stakeholders involved in water management in the project (organization chart, responsibility of stakeholders, level of water management). Water allocation plan is made for dry- season cultivation, but not provided for wet season cultivation. However, the plan is fixed with few changes to the piratical situation of water allocation and actual water requirement in each cultivation stage. An active monitoring of water allocation was also not found in the project. Based on observation on water allocation practice, the reservoir is operated mainly for dry season cultivation, but rarely operated during the wet season cultivation, except land preparation and transplanting and dry spell of the rain. The constraints of the project can be summarized as follows; limited budget, limited funds, limited experience and capability of staff, poor condition of irrigation infrastructures, insufficient vehicles to facilitate work, weakness in water user groups (WUGs) functioning. The results of the focal group discussions and interviews show that the main problems in the area are low production, insufficient water supply and high cost of production. The suggestion to improve this situation includes the provision or introduction of improved farming technology through training and extension and improved water management. The recommended solutions include strengthening of WUGs through intensive education and involvement of membership improves financial transparency and strict implementation of roles, rules and regulations (RRR). Solving poor condition of irrigation facilities can be done by repairing irrigation canals and structures, strict implementation of the RRR and increase of repair funds through better Irrigation Service Fees (ISF) collection.

Keywords: Stakeholders, water resources management, water requirement, reservoir operation, Nam Houm Reservoir.

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X

Vol 19, No. 8;Aug 2012

1. Introduction

Water is essential for human and animal survival in the world. Among those, the Lao PDR is well endowed with water resources and has no expectation of water shortages, except at the local level. Nonetheless, the government is well aware of the need to husband its water resources, as one of the nation's few comparative advantages for economic development. In recent years, Government of Laos (GoL) has moved significantly to develop its water resource management capacity. The GoL plays an essential role for protecting forest areas in water resource management and is widely appreciated; the improved protection of upland catchments is a prominent feature of policy for a variety of downstream benefits especially agriculture and hydropower. Among these, the Nam Houm River is the one of the main tributary of the Nam Ngum River which has provided the basis of population stability and civilization at Naxaythong district in Central part of Lao PDR by constructing invaluable water structure; Nam Houm Dam, which provides controllable water release pattern over the year and serves about 1,500 hectares (ha) of paddy field in dry season. According to the project, 2,400 ha could be fully cultivated if the reservoir is filled up with full capacity at 60 MCM (1 MCM $=10^6$ m^3) at the end of rainy season. Currently, the Nam Houm Irrigation Project is fully turned-over to the Nam Houm water user association (WUA) for operation and maintenance including the ownership of the system (MRC, 2006; DOI, 2007).

However, the processes have not been made smoothly and yet successful because there are a lot of challenges, and issues still remaining. These problems include poor and deterioration of existing irrigation, lacking of stakeholders' incentive due to low income from rice cultivation caused by uncertainty and unavailability of market particularly in the rural area, and cropping intensity in the dry season under irrigation which is still low. In other words, farmers are not willing to grow rice in dry season and this results in the serious problem of cost recovery. The government, therefore, currently is working on rehabilitation of existing facilities appareling with strengthening of WUA to recover and upgrade their function before Irrigation Management Transfer (IMT) is materialized. But Communities are not able to manage assets sustainably. Irrigation schemes are not well maintained and water user organization is very weak. Scheme infrastructure depreciates rapidly with the lack of maintenance and repair resulting in investment intensive rehabilitation cycles of usually less than 10 years. Village development funds (VDF) have in general failed to contribute to irrigation maintenance and development and IMT has not improved system sustainability.

It seems that, the issue of the above objectives for stakeholders in water management in the project is a prime importance. The review and analysis of different participatory irrigation management to reflect the essentials differences between: the old land, new land and mega project could be differences in the level of participation, stakeholders, and financial sources and mechanisms. Today, water resources management is seen as an ongoing process and different stakeholders as an essential part (Grimble & Chan, 1995; GWP, 2000; Molobela & Sinha, 2011). Stakeholders need to participate in water management to effectively integrate the goals of efficiency, sustainability and equity a broad cross section. Supporting stakeholders in managing their water resources to make choice and to reach a common understanding on the necessary arrangements for sharing and allocating water-related goods and service is the basis on which stakeholders have to seek a well-informed decision (Heathcote, 1998; Chenoweth, et al., 2002). The various methods were developed to help express the value of water-related goods and services in quantitative, monetary units (Rogers, et al., 1998). The investigation along with the questions on conceptual model, stakeholder participation and institutional arrangements through which the operation of the canal was mediated (Svubure et al., 2010). To make the transition to more sustainable water management, most analysts recommend managing water based on river basins and increasing stakeholder participation in water management (Wester et al., 2003).

Several of case studies are not full comprehensive, in that they cannot represent every activities which needs to be in a stakeholder participation strategy. However, they do represent a broad cross section of some of the issues and challenges.

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X
Vol 19, No. 8;Aug 2012

This study thus proposes a common linking issue of concern, such as: (i) system infrastructures; (ii) environmental change; (iii) water allocation; (iv) assessment of water requirement for different agricultural activities; (v) in flow and out flow assessment; and (vi) responsibility of stakeholders. This study will also present the field activities in the pilot project: Nam Houm Irrigation Scheme to update information by undertaken field observation and data collection. Collection of primary data for Strength, Weakness, Opportunity and Threat (SWOT) analysis population and random sampling using questionnaires for interviewing of the groups sampling such as the group of farmers, water masters, block leaders which are formulated above. The interview will identify major factors as follow: institutional factors interview the groups sampling and review the government policy to the WUA; Technical factors interview the technical staffs and review the design and construction drawings of the scheme, Socio-Economic factors Interview with public and private stakeholders' interview with individual farmers of the group sampling.

2. Methodology and Approach

The pilot project of this study is the Nam Houm Irrigation Scheme, Laos PDR. The location and Schematic plan of the study area are shown in Figures 1 and 2. The methods are presented as the follow.

2.1 Assessment of Water Requirement:

The water requirement is appraised using all parameters conducted in the fields. Those parameters are described as follows.

2.1.1 Evaporation, ETo

The ETo was recorded using A-pan instillation in the study area. The data was recorded on daily basis and the recorded results are made available in Nam Houm Irrigation Scheme Organization (NISO) for both dry and wet seasons. The ETo is not used for calculation of ETc of paddy since the ETc of paddy is directly measured in the paddy field. The ETo is used for calculation of ETc for cash crops.

2.1.2 Rainfall

Rainfall (R) was recorded by installation of simple rain gage at the same place as ETo as installed. The recorded results are provided in separated documents.

2.1.3 Crop Coefficient, Kc

The Kc is referred from the book of water requirement (MAF). The Kc of paddy in dry and wet seasons was distinguished.

2.1.4 Evapo-Transpiration, ETc and Percolation

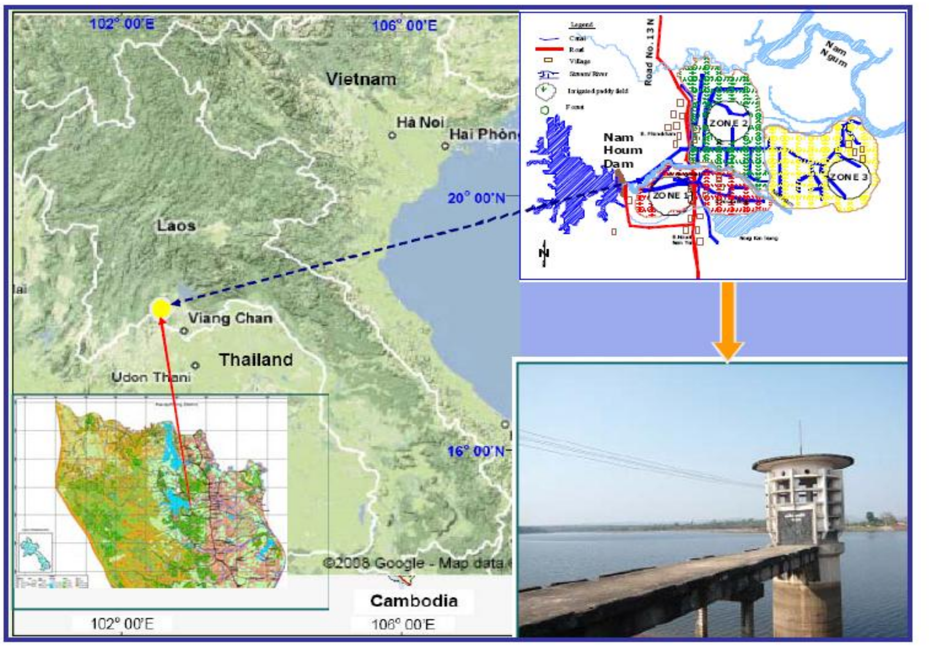
The ETc and Percolation were directly recorded in the paddy field by installation of equipment shown in Figure 3. The water levels which include ETc and Percolation were recorded every day through the dry and wet seasons. The installation was made in 3 places at up-, middle-, and down-stream commanded areas. The data used for the calculation was the average of these 3 stations.

The ETc of paddy is also cross checked with data calculated from ETo (ETc = ETo x Kc). The Kc was mentioned above.

The ET of fish pond is calculated by installation of staff gauge in 2 fish ponds at up- and middle-stream command area. The water level of fish pond which consists of ET of fish pond and percolation was recorded every day. The inflows and outflows of fish pond during water level monitoring were controled and recoded in order to obtain water level properly. The water level of fish pond data is used as water requirement for fish pond.

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X
Vol 19, No. 8;Aug 2012

Figure 1. Location of the Nam Houm irrigation project, Lao PDR.



2.1.5 Identify actual planted area

Identification of actual irrigated areas was observed in dry and wet seasons. The GPS was used to record points and boundaries of actual irrigated areas. The head of WUGs were interviewed to mark their own actual boundary of irrigated areas. The collected information was then plotted into schematic ground plan of irrigation scheme. The actual irrigated areas were monitored every 10 days. The actual planted areas were used to calculate system water requirement.

2.1.6 Cropping pattern and crop calendar

The data collection will be done and provided to each water user group to record cropping pattern and crop calendar for their own groups. The information will be crosschecked by conducting field observation for 2 times in dry season and for 2 times in wet season. This information includes: kinds and hectares of crops to be grown; date/time and length (number of days) of land preparing, translating and harvesting periods.

2.1.7 Water requirement for different agricultural activities

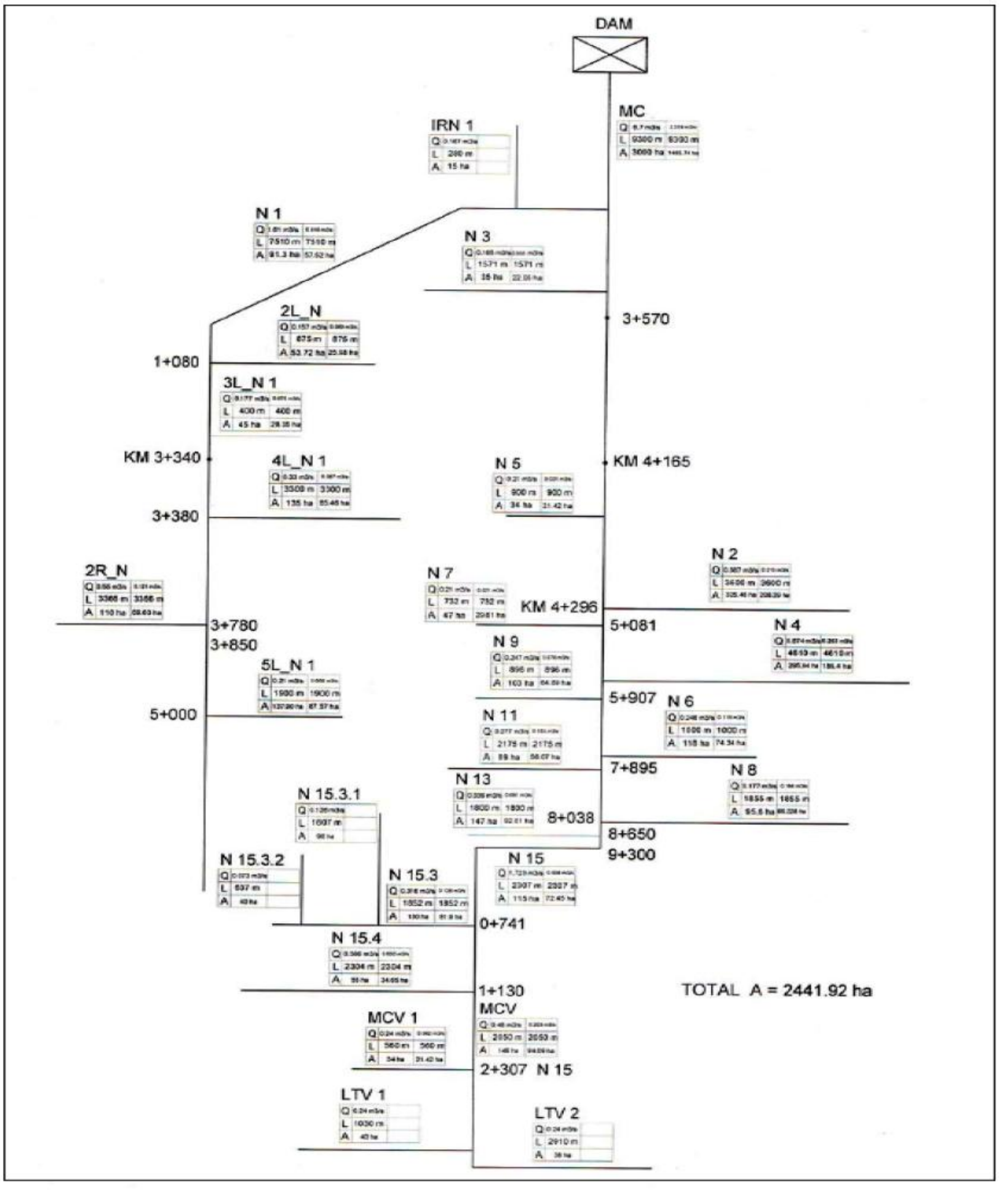
Because of various agricultural activities are practiced in the project, therefore the water requirement (WR in mm.day^{-1}) for each agricultural practice was calculated by the following equations. Water requirement for paddy:

$$WR_p = ET_0 \times K_c + P + L_P \qquad (1)$$

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X

Vol 19, No. 8;Aug 2012

Figure 2. Schematic plan of Num Houm Irrigation project.



WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X

Vol 19, No. 8;Aug 2012

Figure 3. ETc Installation.

(a)

(b)

Water requirement for non-paddy crops (cash crops):

$$WR = ET \times Kc \quad (2)$$

Water requirement for fishponds:

$$WR\ f = ETo \times Kc + P \quad (3)$$

Where: ETo is potential or reference evapo-transpiration ($mm.day^{-1}$), Kc is crop coefficient (dimensionless), LP is land preparation ($mm.day^{-1}$), P is percolation ($mm.day^{-1}$).

Percolation is considered when calculating water requirements for paddy and fishpond. However, percolation is assumed to be minor and neglectible when calculating water requirement for cash crops.

2.2 Inflow and outflow measurements

To access water balance, flow measurement points were determined to scope with all inflows and out flows. Not only flows from irrigation canals were measured, all natural inflows and outflow were covered. The measured data in each canal is provided in separated documents.

The measurements in irrigation canals were conducted according to the irrigation schedule of the project or gate operation at the intake of each canal, but mostly with average for 2 times a month. One time spends time approximately for 7 days for measurement. Measurement teams were divided into 2 teams, one team conducted flow along canal system and the other team conducted flow measurement at natural steams.

The current meter is provided by MRCS to conduct flow at canals. Figure 4 shows the field work of the team conducting flow measurement at main (left) and tertiary (right) irrigation canals.

The methodology of flow quantity calculation was by following the instruction provided by Mekong River Commission Secretariat (MRCS) and Department of Irrigation (DOI) with the brief explanation as follows.

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X

Vol 19, No. 8;Aug 2012

According to Figure 5, measurement was conducted along the vertical depth of 0.2, 0.6, and 0.8 in each divided segment at cross section area. In case when water level is lower than 0.6 m, only 0.2 and 0.8 of depth was measured. The average velocity was calculated in each segment, and then discharge of each segment was calculated with each cross section area (a_i) and average velocity (v_i). The total discharge at each measurement point is to sum up of discharge of each segment cross section area.

Figure 4. Flow Meter Equipments and Flow Conducting.

(a)

(b)

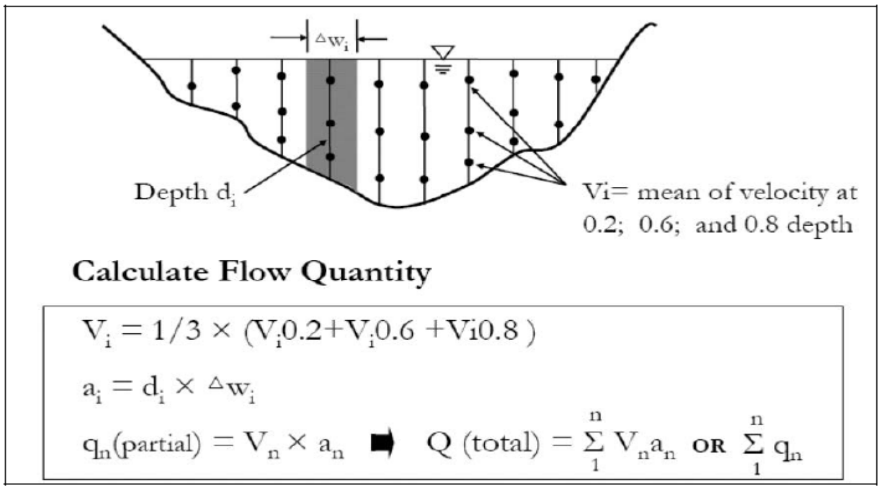
(c)

(d)

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X

Vol 19, No. 8;Aug 2012

Figure 5. Calculation of Flow Quantity.



3. Results and Discussion

3.1 Statistic data analysis

3.1.1 Evaporation (ETo)

Figure 6 shows the monthly average of ETo recorded from November 2008 to October 2009. The average ETo was estimated at 3.32 mm.day^{-1} in dry season and 4.47 mm.day^{-1} in wet season. The ETo is generally lower in dry season from November to June and higher in wet season from June to October. The higher humidity in wet season might be the reason of the high ETo. The peak is clearly observed in February in dry season and in August in dry season. The daily recorded value is provided in separated documents.

3.1.2 Rainfall

The Figure 6 also shows the rainfall observed at the same period. Almost no rainfall was observed in dry season of 2008/09. The average rainfall in dry season was 0.07 mm.day^{-1}, while 21.09 mm.day^{-1} in wet season. The peak time of rain occurred in the in 2009 (in September), while it usually occurred in July or August in normal years. The total rainfall is also slightly lower than usual with 1,395.10 mm (3.2 mm in dry season), while approximately 1,700 mm which was the average from 1987-2007 recorded by the DMH at Vientiane Capital.

3.1.3 Effective Rainfall

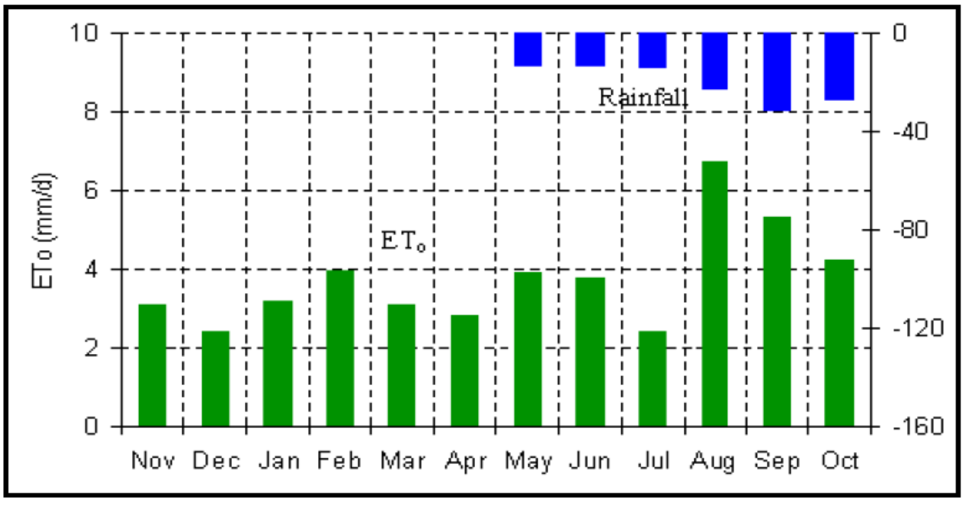
The effective rainfall was estimated according to the following details:

$$R_e = 0.8P - 25, if...P > 75mm/month$$
$$R_e = 0.6P - 10, if.....P < 75mm/month \quad (4)$$

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X

Vol 19, No. 8;Aug 2012

Figure 6. Evaporation and Rainfall.



The total effective rainfall estimated for dry season is 0.048 MCM, but 19.79 MCM in wet season. The effective rainfall is used to calculate overall command area efficiency.

3.1.4 Evapo-transpiration (ETc)

The calculated ETc is shown in Figure 7 covering dry and wet seasons. The average of 4.03 $mm.day^{-1}$ was obtained in dry season and 6.33 $mm.day^{-1}$ in wet season. The high period of ETc occurred from February to March for the dry season and from September to October in wet season. The ETc is generally higher in wet season. The high humidity and temperature in wet season might be the reason of the high value. The ETc was recorded in 3 stations within the command areas at up-middle, and downstream command area.

3.1.5 Deep Percolation

The Figure 7 also shows the average monthly percolation recorded in the same station with ETc. The percolation is higher in dry season (3.21 $mm.day^{-1}$), but only 1.19 mm/d in wet season. The reason could be the height of ground water level in wet season resulting in the low percolation in wet season. The high percolation is also observed in the command areas located near to the Nun Ngum river bank. The difference of soil types in the command areas might be the factor of different percolation rates.

The highest percolation is observed in March and April when the climate is the hottest in Laos. The percolation in wet season was gradually reduced from the beginning to the end of cultivation stages.

3.1.6 System Water requirement

Taking all items considered above, system water requirement is calculated and results are summarized in the Table 1. Total crops water requirements for dry season was estimated at 10.13 MCM (6,638.92 $m^3.ha^{-1}$ or 663.90 mm) at on-farm level. Of these total requirements, it was accounted for paddy requirement of 96. 95%, cash crops of 0.78%, and fishpond of 2.27%.

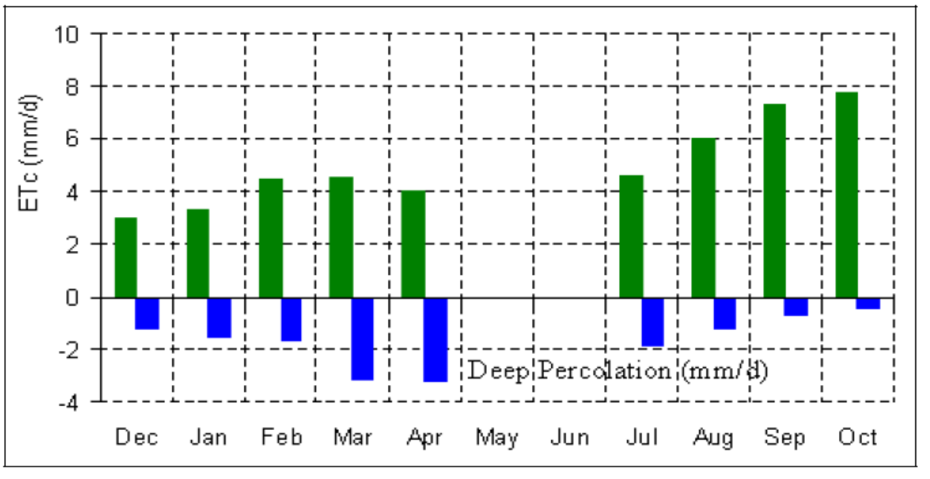
In the wet season, as much as twice of dry-season value is estimated (20.67 MCM). That is 9,133.09 m^3/ha, or 913.7 mm. The higher water requirement in this season is due to longer days of rice variety, higher ETc, and larger planted area of paddy. Lesser amount is required for cash crop in wet season

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X

Vol 19, No. 8;Aug 2012

because of few planted areas, while demand for aquaculture is almost constant between dry and wet season.

Figure 7. Evapotranspiration and Deep Percolation.



If considering 69.07% of conveyance efficiency conducted in the project, the total water requirement at headwork or main intake is counted for 9,621.62 $m^3.ha^{-1}$ in dry season and 13,236.36 $m^3.ha^{-1}$ in wet season. These values are significantly low compared with standard value which is being used by the project of 20,000 $m^3.ha^{-1}$. So far, no detail experiment was conducted; the standard value has been borrowed from other sources, according to the project manager.

Table 1. Water Requirement for each agricultural activity.

Water requirement for each agricultural activity		Dry season	Wet season
Paddy (MCM)		9.817	20.370
Cash crops (MCM)		0.078	0.006
Aquaculture (MCM)		0.234	0.296
Total	MCM	10.129	20.672
	mm	663.90	913.70

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X
Vol 19, No. 8;Aug 2012

3.1.7 Water Requirement and Irrigation Water Supply

The reference crop evapo-transpiration (ETo) were calculated based upon the Modified Penman method by Doorenbos and Pruitt 1977; FAO Irrigation and Drainage Paper 24 and the lasted modified Penman-Monteith method by Mr. Smith 1998 (Allen et al., 1998).

3.2 Determination Procedure

(1) Determine the evapo-transpiration (ETo), data from Irrigation Water Requirement of Vientiane Irrigation Plan.

(2) The second stage in estimating crop water requirements is the selection of the crop coefficient (Kc) according cropping pattern during a production season and the growth characteristics of the crop. Then ETcrop is equal to Kc ETo for each periods through the growing season depending on the chosen budgeting period for the application of water to supplement any rainfall.

Crop growing period and crop coefficient Kc, by Penman-Monteith method:

Land preparation and nursery stage Kc = 1.2 to 1.15; Initial/Development stage Kc = 1.0 to 1.01; Medium stage Kc = 1.05; Last stage/harvest; Kc = 1.01 to 0.84

(3) Consumptive use or Crop evapo-transpiration, Etc = ETo x Kc (mm.day^{-1})

(4) Deep percolation DP (mm.day-1) from soil percolation test = 7.87 (mm.day^{-1})

(5) Determine the effective rainfall. Re (mm.day^{-1})

(6) Determine Area under LP/N ,ALP/N (ha)

(7) Land preparation/Nursery , LP/N: 180mm.

(8) Land preparation/ Nursery Requirement = (3)+(4)+(6) - (5) (mm.day^{-1})

(9) Net Water Duty for LP/N = (8)*0.1157 (l.sec^{-1}.ha^{-1})

(10) Water Requirement for LP/N) = (9)*(6) (l.sec^{-1})

(11) Determine Area under Crop Water Requirement, ACWR (ha)

(12) Crop Water Requirement, CWR = (3)+(4) - (5) (mm.day^{-1})

(13) Water Duty for CWR = (12)*0.1157 (l.sec^{-1}.ha^{-1})

(14) Water Requirement for CWR = (13)*(11) (l.sec^{-1})

(15) Net Duty of Water = (10)+(14)

(16) Gross Duty of Water at 60% Efficiency = [(15)*100]/60 (l.sec^{-1})

(17) Gross Duty of Water per hectare = (16)/Irrigated Area (l.sec^{-1}.ha^{-1})

Figures 8 and 9 show the daily and weekly water requirement against irrigation water supply for dry and wet seasons. The water supply is calculated at the on-farm level based on the actual flow data at the main intake multiplied by conveyance efficiency (69.07%) conducted in the project.
In the dry season (Figure 8), high water requirement is observed at the land preparation and transplanting period from November to mid December. The peak water requirement is obtained at the end of February to End of March, while the lowest value appeared in development stage from mid December to beginning of January. As compared to irrigation water supply, there is a big gap between required and supplied amount. The water supply is generally higher than supplied amount, particularly from mid December to Beginning of February. The low requirement by crops is observed, but high supply was made in this period. The highest supplied period is found is in March when paddy crop is

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X

Vol 19, No. 8;Aug 2012

in flowing stage and the hot climate starting.
In the wet season (Figure 9), the estimated water requirement is largely fluctuated. The heavy rainfall affects to the observed value and it is difficult for estimation. The high water requirement is clearly observed, mainly from beginning of September and beginning of October. The irrigation was not supplied for the whole wet season, but as supplementary for land preparation and transplanting stage from May to July. For the rest stages, the supply water is filled by natural inflows, but mainly rainfall.

3.3 Project water management appraisal

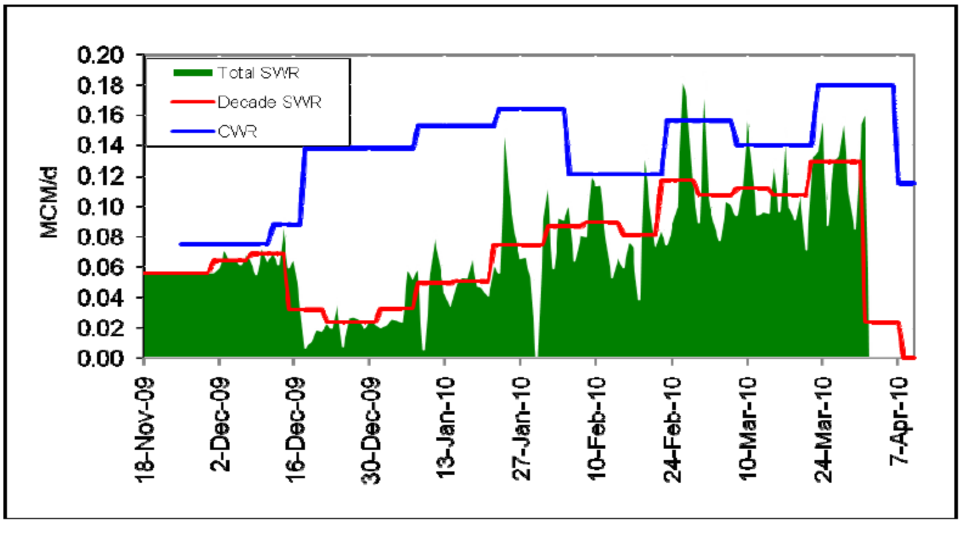
3.3.1 Stakeholders involved in water management in the project:

The Num Houm Irrigation Project is jointly managed by government and farmers. Therefore, stakeholders involved in water management in the project consists of the MAF level down to farmer organizations. The management appraisal of the project is described as follows:

(1) Organization chart

The project is operated by Num Houm project office belonged to the PAFSOs of Vientiane capital under the Ministry of Agriculture and Forestry. As shown in organization chart in Figure 10, there are 4 main units under Num Houm project office namely agriculture and extension unit, irrigation unit, livestock unit and forestry unit. Irrigation unit is fully responsible for irrigation water management through 3 Water User Associations (WUAs). There are 11 water user groups (WUGs) in total working under WUAs, of these permanent members are 960 persons and temporary members are 380 persons. The agriculture service unit supports mainly for agricultural extension work such as training on agriculture production, technical on fertilizer application, pest and disease protection, etc.

Figure 8. Water Requirement and Water Supply at Field Level (Dry Season).



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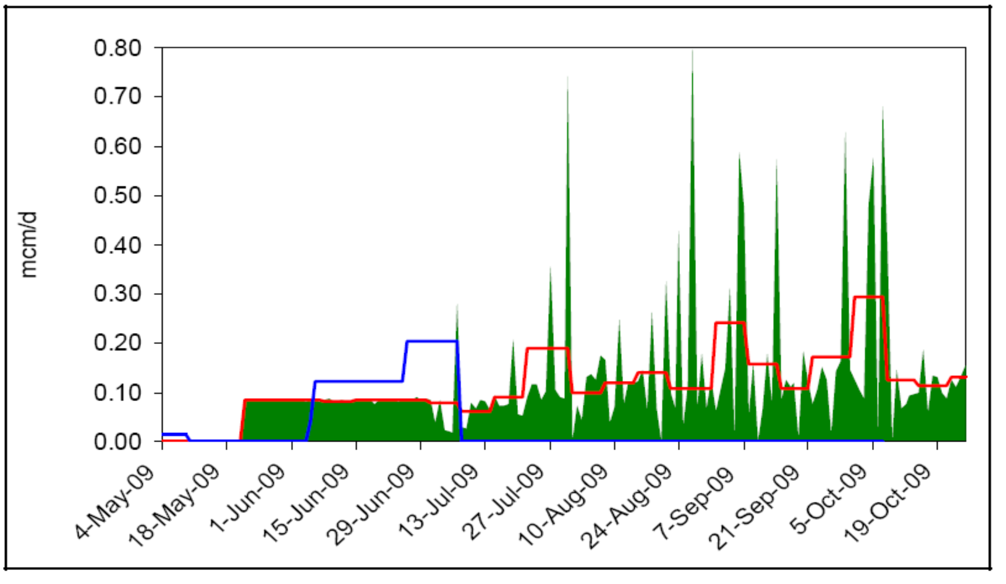
Vol 19, No. 8;Aug 2012

Figure 9. Water Requirement and Water Supply at Field Level (Wet Season).



(2) Responsibility of stakeholders

At office level, project is being managed by 6 officials in irrigation unit including Head, Deputy Head, 3 irrigation engineers, and 1 agriculture extension staff. The Head and the Deputy Head oversees the overall management and supervision of Operations and Maintenance (O&M) work. Each irrigation engineer is assigned to supervise O & M work for each Water User Association (WUA). The responsibilities of level include: O&M of the dam and reservoir, O&M of main canal. Arrangement of budget proposal for major repairs of all irrigation facilities and structures within the scheme, this proposal is submitted from the District level to Provincial level and then to Central Government.

Overall planning and supervision of the water allocation include planning, implementation, monitoring and evaluation, and Coordination with the district and provincial government for emergency repair needs of the scheme.

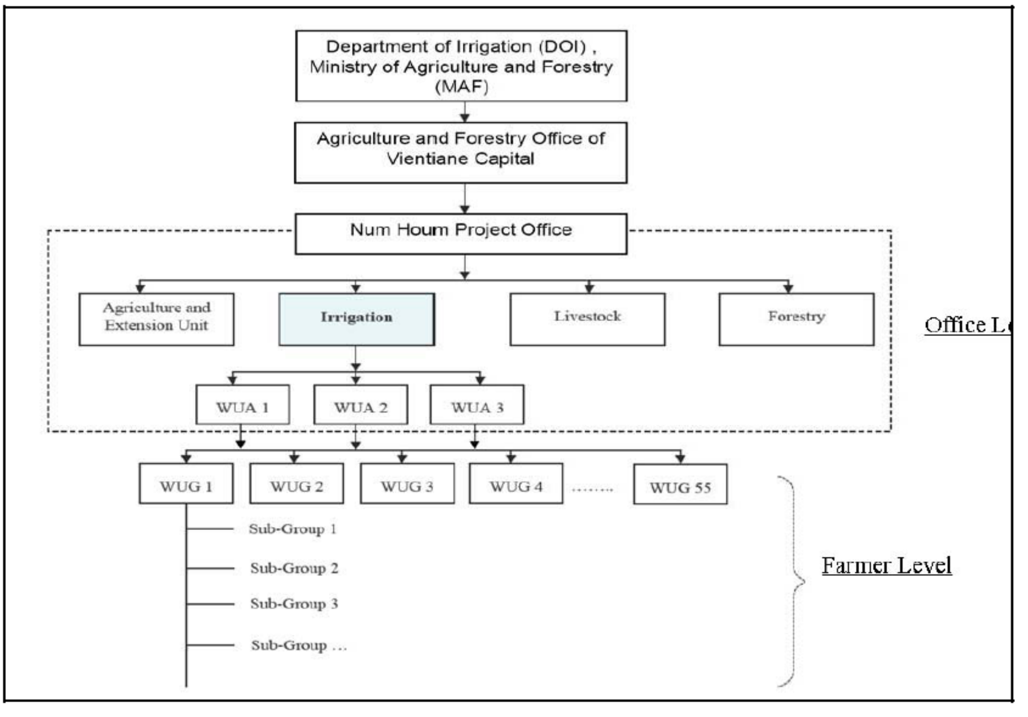
At farmer level, the O&M work is under responsibility of WUGs (55 WUGs as total). The responsibilities cover the O&M work from intake of secondary canal. The steering committee is formed with 1 project official (WUA), WUG head (farmer), and chiefs of the villages that command area belong to. The steering committee performs the functions of planning, problem-solving, decision-making, supervision, and technical assistance.

The organizational set-up of the WUGs consists of a leader, two deputies, and one accountant. The main task of this level is the responsibilities for water distribution, routine maintenance, and assisting unit group to collect Irrigation Service Fees (ISF). The detailed responsibilities of WUGs are listed below. Coordination and under supervision of WUAs for irrigation schedule is done by planning, monitoring water distribution, maintenance of major repairs of irrigation facilities and structures within the boundary-command areas from secondary canals to farm level, collection of ISF and remittance of ISF collected from farmers to the project, and monitoring progress-planted area under boundary of WUG to estimate ISF collection.

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X

Vol 19, No. 8;Aug 2012

Figure 10. Organization Chart of Num Houm Irrigation Project.



The O&M work lower than above level is unit group which consist of one head and one deputy. The group has responsibilities of O&M work at on-farm level from intake of tertiary canal.

(3) Level of water management

The water management and service are conducted as following procedures. The reservoir and the main canal operation is responsibility of the WUAs under the project office. The WUGs are responsible for operating of the secondary canal level coordinating with the project office and their unit groups. The unit groups cover activities at the tertiary and on-farm level. The beneficiary household is summarized Table 2.

3.3.2 Water allocation plan and practice:

Water allocation plan is made for dry- season cultivation, but not for wet season cultivation. However, the plan is fixed with few changes or not much fallibility adapted to the piratical situation of water allocation and actual water requirement in each cultivation stage. Active monitoring of water allocation was also not found in the project.

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Table 2. Beneficiary Households.

Groups	Beneficiaries		
	No.of Village	Total Households	Beneficiary persons
WUA1 (N1)	7	441	4,970
WUA2 (RMC)	6	501	7,559
WUA3 (LMC)	6	644	7,821
Total	19	1,586	20,350

Based on observation on water allocation practice, the reservoir is operated mainly for dry season cultivation, but rarely operated during the wet season cultivation, except land preparation and transplanting and dry spell of the rain. The simple rotation method is applied at the main canal level by diving command areas into 2 parts zones as shown in Table 3: (1) left side of the main canal that delivering the areas of N1, 2LN1, 3LN1, 4LN1, 2RN1, 5LN1 with total areas of 335.24 ha in dry season 2009/10. the supply schedule is from Monday to Thursday, and (2) right side of main canal that delivering the areas under N3, N5, N7, N9, N11, N13, N15, N15.3, N15.4, MCV1, N2, N4, N6, N8 and MCV with total of 1,125.42 ha. The water delivery is from Friday to Sunday.

3.3.3 Project constraints and Problems

According to the project, the constraints can be summarized as follows:

(1) Limited budget due to poor ISF collection and limited funds from the provincial or central government,

(2) Limited experience and capability of staff,

(3) Poor condition of irrigation infrastructures,

(4) Insufficient vehicles to facilitate O&M work,

(5) Weakness in WUG functioning, especially that WUG3 is not functioned as planned,

(6) Some WUG's boundary command area is too large that is 550 ha with more than 600 beneficiaries, making it difficult to manage.

The results of the Focal Group Discussions and interviews show that the main problems in the area are:

(1) Low production due to poor soils; poor seed quality; pest and diseases infestation; insufficient water supply and high cost of production. Suggestion to improve the situation includes provision or introduction of improved farming technology through training and extension and improved water management

(2) Weak WUA – weak cooperation of members; weak implementation of the WUG Roles, Rules and regulations, poor transparency of financial transactions (financial reports not religiously prepared and not informed to members); poor monitoring and recording of irrigated areas and ISF payments. Recommended solutions include strengthening of WUGs through intensive education and involvement of membership, improving financial transparency and strict implementation of RRR.

WULFENIA JOURNAL KLAGENFURT, AUSTRIA ISSN:1561-882X

Vol 19, No. 8;Aug 2012

Table 3. Canal system.

No.	Name of Canal	Length (m)	Designed	
			Area (ha)	Discharge (m^3/s)
1	IRN1	280	15	0.167
2	N1	7,510	91.3	1.610
3	2L-N	875	53.72	0.157
4	3L-N1	400	45	0.177
5	4L-N1	3,300	135	0.330
6	2R-N	3,366	110	0.550
7	5L-N1	1,900	137.9	0.210
8	MC	9,300	428.08	6.700
9	N2	3,600	325.46	0.567
10	N3	1,571	35	0.165
11	N4	4,610	295.94	0.874
12	N5	900	34	0.210
13	N6	1,000	118	0.246
14	N7	732	47	0.210
15	N8	1,855	95.6	0.177
16	N9	896	103	0.247
17	N11	2,175	89	0.277
18	N13	1,800	147	0.339
19	N15	2,307	115	1.723
20	N15-3	1,852	130	0.316
21	N15-3-1	1,607	90	0.126
22	N15-3-2	637	40	0.073
23	N15-4	2,304	55	0.386
24	MCV	2,050	149	0.480
25	MCV1	560	34	0.240
26	LTV1	1,030	43	0.240
27	LTV2	2,910	38	0.240
	Total	61,327	3,000	17.037

(3) Poor condition of irrigation facilities and structures due to limited funds for repair, poor maintenance, cases of vandalism (destroyed gates, animals going in and out of canals), and lack of distribution ditches for some farms. To resolve this, repair of irrigation canals and structures is necessary; and there should be strict implementation of RRR and increase of repair funds through better ISF collection.

(4) Decreasing water supply – due to degradation of watershed. To resolve this situation the watershed must be protected and improved.

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Vol 19, No. 8;Aug 2012

4. Conclusions

This study presented a water resources linking issue of concern such as system infrastructures, environmental change, water allocation, assessment of water requirement, flow measurement and responsibility of stakeholders. The field activities in the pilot project of Nam Houm Irrigation Scheme, Laos PDR was presented to update information by undertaking field observation, interviewing stakeholder and collecting data.

It is found from the results that water requirement is appraised using all parameters conducted in the fields such as evaporation, ETo, rainfall, crop coefficient, evapotranspiration, percolation, identify actual planted area, cropping pattern and crop calendar. The water management appraisal was conducted to stakeholders involved in water management in the project considering organization chart, responsibility of stakeholders and level of water management. Water allocation plan is made for dry-season cultivation only, but also not provided for wet season cultivation. However, the plan is fixed with few changes to the piratical situation of water allocation and actual water requirement in each cultivation stage. An active monitoring of water allocation was also not found in this project.

The observation data show that, the reservoir is operated mainly for dry season cultivation, but rarely operated during the wet season cultivation, except land preparation and transplanting and dry spell of the rain cases. The constraints of the project can be summarized as follows; limited budget, limited funds, limited experience and capability of staff, poor condition of irrigation infrastructures, insufficient vehicles to facilitate work, weakness in water user groups (WUGs) functioning.

The results of the focal group discussions and interviews were shown that the main problems in the area are low production, insufficient water supply and high cost of production. The suggestion to improve this situation includes provision or introduction of improved farming technology through training and extension and improved water management. The recommended solutions were to include strengthening of WUGs through intensive education and to involve membership, to improve financial transparency, to implement roles, rules and regulations (RRR) strictly. The poor condition of irrigation facilities were resolved by repairing irrigation canals and structures, strict implementation of the RRR and increase of repair funds through better Irrigation Service Fees (ISF) collection.

5. Acknowledgements

The authors would like to express their appreciation to the Faculty of Engineering, Mahasarakham University for financial support, Mekong River Commission Secretariat (MRCS) and Department of Irrigation (DOI), Lao PDR for supporting data.

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American Journal of Engineering and Applied Sciences

ISSN: 1941-7020

e-ISSN: 1941-7039

Type: Quarterly

Description

American Journal of Engineering and Applied Sciences, an international journal publishes four times a year in print and electronic form. AJEAS is a peer reviewed technical journal publishes original research contributions and is an unparalleled resource for key advances in the field of engineering. Scope of the journal includes but not limited to applied physics and applied mathematics, automation and control, biomedical engineering, chemical engineering, civil engineering, computer engineering, computer science, data engineering and software engineering, earth and environmental engineering, electrical engineering, industrial engineering and operations research, information technology and informatics, materials science, measurement and metrology, mechanical engineering, medical physics, power engineering, signal processing and telecommunications.

Current Issue (Volume: 5 , Issue: 3 2012)

COMPOSITE CONTENT MANAGEMENT-CASE MANAGEMENT AND ENTERPRISE CONTENT MANAGEMENT

Lekha Menon

Page Numbers: 219-229
Publication Date: August 29 2012
DOI: 10.3844/ajeassp.2012.219.229

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Publication Date: August 29 2012
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American J. of Engineering and Applied Sciences 2 (1): 133-138, 2009
ISSN 1941-7020

A Varied-Utilized Soil Type in Linear Programming Model for Irrigation Planning

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Abstract: Problem statement: Optimal crop pattern with maximum profit is important information for irrigation planning using optimization model. Crop yield, crop water requirement, man power, production cost and physical soil type are required to the search model. A consideration varied-utilized soil type directly influences to the profit of obtained crop pattern. **Approach:** The objective of this study is to find an optimal crop pattern for irrigation planning in a varied-utilized area of the Van Vieng Phi irrigation project, Khammouan province, Central Region of Lao PDR. An allocation Linear Programming (LP) model was applied to find the optimal crop pattern in dry-season (November-April). The considered irrigation project was divided into several sub-areas, based on suitable soil type of each crop representing the varied-utilized character. The existing suitable soil type of each crop was used to represent the varied-utilized in term of water requirement and crop yield for each sub-area. The records of seasonal flow from pump station, requested and actual implementation of irrigation area, crop water requirements, evaporation, percolation and effective rainfall were used for this illustrative application. **Results:** The results have shown that the net benefit of varied-utilized character and unvaried-utilized character (existing consideration) were obvious difference. The obtained crop pattern of the proposed model corresponded to the suitable soil type for cultivation crops. Furthermore, the results presented that the proposed model gave higher net benefit than the existing unvaried-utilized character. **Conclusions/Recommendations:** The consideration several sub-areas of irrigation project based on suitable soil type in LP model can be represented the varied-utilized character. The proposed LP model is appropriately for finding the optimal crop pattern for irrigation planning.

Key words: Optimization model, linear programming, irrigation planning, crop pattern

INTRODUCTION

An allocation of limited available resources is one of the classical problems in water resources management. In particular, given the total available resources for example water, soil, land area and manpower, one would like to know what proportion of the available resources should be given to each considered crop in an irrigation project in order to maximize the total profit of agricultural activities. With optimization techniques available; such as Linear Programming (LP), Dynamic Programming (DP) and Genetic Algorithm (GA), it is LP model that is more popular because of the proportionate characteristic of the allocation problems. The formulation of the LP model to the problems usually assumes that crop water requirement and crop yield of all soil types in the considered project be homogeneous value for all seasons. Unfortunately, the assumption often leads to serious error in the optimal solution of the crop pattern.

In Lao PDR, improving performance of irrigation planning for an operation and maintenance project is an obvious issue for agricultural development and water resources management. The Vang Vieng Phi Irrigation scheme is a Pump Irrigation System, which located in Se Bangfai district about 45 Kilometers south of Thakhek, Khammouan province. The irrigation scheme is designed for an irrigation service area of 1,086 hectares during the wet season and 1,070 hectares during the dry season. Record of irrigated area from 2000-2007 presented that the scheme had been irrigating an average of 229.55 hectares during the dry season or a 21.45% of the dry season design area. The highest dry season irrigated area is recorded in crop year 2006-2007--359.74 hectares or 33.62% and the lowest in 2004-2005--121.79 hectares or 11.38%. The record shows that the dry season irrigated area had been increasing from crop year 2000-2001 to 2002-2003 but this started decreasing from then to 2003-2004 and increased again from crop year 2005-2006 to 2006-

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2007. The decreasing trend from 2002-2003 is due to the increasing cost of electricity and hence high Irrigation Service Fee (ISF) for farmers. The increase in 2005-2007 more likely is brought about by the 25% decrease in electricity rates declared by the government[1].

In consequence, before starting of each irrigation season, an operation and maintenance staff of the irrigation scheme should prepare appropriately of irrigation planning to ensure that required total of land-area from the farmers for each seasonal cultivation and how much water to be distributed into paddy fields. Also the irrigation facilities and structures should monitor time to time. For this reason, the repair of irrigation canals and structures is necessary. Oppositely, the farmers need to have the optimum cropping pattern which will maximize the economic return.

Often, most irrigation projects lacked satisfactory tools for finding the optimal crop pattern that considering crop yield from crop water requirement and appropriate physical soil type. The crop yield is usually affected by crop water requirement and physical soil type which suitable for cultivation of each crop. As a result the obtained pattern is inappropriately with soil type, so consequences are increasing production cost, using chemical fertilizer and pesticide and increasing pollution[2].

In accordance with the above constraints issued, the project needs to improve irrigation planning before starting of each irrigation season in order to maximize the total profit of agriculture activities.

A linear programming is an optimization technique which widely used to allocate the limited water resources because of the proportionate characteristic of allocation problem[3-5]. Furthermore, the LP is easy to apply with the problem of irrigation planning using several available programs.

The maximization benefit was set as the objective function based on the resources constraints. The constraint functions are linear equation for finding optimum crop pattern when given available water[6-7]. For finding optimum crop water requirement when given available water[8]. A different portion price of irrigation water is considered in constraints of LP model[2,9].

The purpose of this study is to propose an allocation LP model that can take into account varied-utilized land area and multi-crop water requirements. The varied-utilized character of the irrigation project will be represented by dividing each crop water requirement and paddy fields into several crops and sub- areas based on suitable soil type for cultivation crop.

MATERIALS AND METHODS

Model formulation: The linear programming is used as a based model for finding optimal crop water requirements and optimal seasonal crop pattern. The model will be formulated to maximize benefit subjected to the limited resources on available water supply which pumped from the river and suitable soil types of each crop. The obtained cropping pattern can be used for seasonal planning which considering the varied-utilized characters of paddy fields.

The objective function of the model can be presented as:

$$\text{Max}Z_j = \sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K} Nb_{hik} X_{hijk} \quad (1)$$

Where:

- Z_j = The gross benefit of the scenario during the season j
- H = Sub-area index of the scenario (h = 1,2,3,….H)
- i = Soil type index (i=1,2,3…I)
- j = Seasonal index j
- k = Crop type (k = 1,2,3…K)
- Nb_{hik} = Net benefit of crop k in sub-area h for soil type i (US$ ha^{-1})
- X_{hijk} = Irrigated area of crop k in sub-area h for soil type i during season j (ha)

The constraint functions of the model can be divided into two categories including water constraint and land area constraint.

The water constraint considered the irrigation efficiency[1,10]. The overall water efficiency of the irrigation project, which described as:

$$e_p = \left(\frac{V_m + V_2 + V_3}{V_C + V_1}\right) * 100 \quad (2)$$

Where:

- e_p = Overall efficiency of the irrigation project
- V_m = Volume of irrigation water needed and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle (m^3)
- V_1 = Inflow from other sources to the conveyance system (m^3)
- V_2 = Non-irrigation deliveries from conveyance system (m^3)
- V_2 = Non-irrigation deliveries from the distributary's system (m^3)
- V_c = Volume diverted or pumped from the river (m^3)

Am. J. Engg. & Applied Sci., 2 (1): 133-138, 2009

$$V_m = SWR - ER \quad (3)$$

$$SWR = \sum_{u=1}^{U} \int_{v=1}^{V} WR_{vu} x A_{vu} \quad (4)$$

Where:
SWR = Total scheme water requirement (m^3)
ER = Effective rainfall (m^3)
WR_{vu} = Crop water requirement (mm day^{-1} x 10^{-3}) of crop type u at the day v
A_{vu} = Actual cultivated area (m^2) of crop type u at the day v

The net crop water requirement is not greater than the total available water of the irrigation scheme multiplying the irrigation efficiency of irrigation project, which described as:

$$\sum_{h=1}^{H} \sum_{i=1}^{I} \sum_{k=1}^{K} CWR_{hijk} X_{hijk} \le e_p V_{Cj} \quad (5)$$

$$CWR = WR_{vu} \text{ x Stage of crop development} \quad (6)$$

Where:
CWR_{hijk} = Crop water requirement rate of crop k in sub-area h for soil type i during season j (mm ha^{-1})
Vc_j = Total available water pumped from the river during season j (Mm^3)

The available water supply during the season of each zone (AWS_{hj}) is calculated by multiplying the net available water of the irrigation system with a proportion of each zone area and total area (T_j), which presented as:

$$AWS_{hj} = e_p Vc_j \left(\frac{X_{hj}}{T_j} \right) \quad (7)$$

$$\sum_{i=1}^{I} \sum_{k=1}^{k} CWR_{hijk} X_{hijk} \le AWS_{hj} \quad (8)$$

For the land constraint, the summation of all zone area is not greater than the available total area of scenario during season j; which described as:

$$\sum_{h=1}^{H} X_{hj} \le T_j \quad (9)$$

In each zone divided into several sub-areas suitable to soil type. The total land area of all soil type is not larger than the available area of the zone, which presented as:

$$\sum_{i=1}^{I} \sum_{k=1}^{K} X_{hijk} \le X_{hj}; \quad \text{for } h = 1,2,3 \ldots H \quad (10)$$

The net irrigated area of all crops is not greater than the land area of each soil type. The irrigated area of each crop is not larger than the suitable area for its cultivation. These constraints are of the following form:

$$\sum_{k=1}^{K} X_{hijk} \le X_{hij}; \text{ for } h = 1,2,3,\ldots H \text{ and } i = 1,2,3 \ldots I \quad (11)$$

$$X_{hijk} \le S_{hijk}; \text{ for } h = 1,2,3,\ldots H;\ i = 1,2,3 \ldots I;\ k = 1,\ldots K \quad (12)$$

$$X_{hijk} \ge 0$$

where, S_{hijk} is amount of suitable land for the cultivation of crop k in sub-area h for soil type i during season j .

In order to consider the varied-utilized character of paddy field of the suitable soil type for cultivation each crop, the zone area is divided into several suitable soil types (Fig. 1).

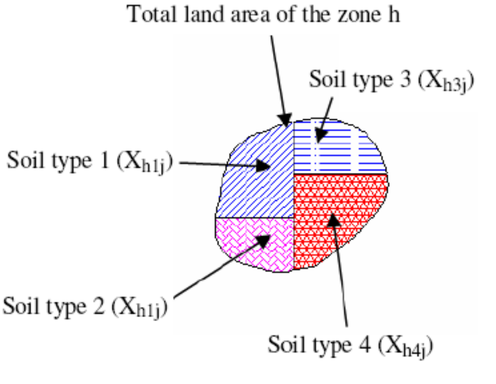

Fig. 1: The suitable soil type for the cultivation in a zone area

Illustrative application: The 7-year (2000-2007) of pump operation, irrigated area, irrigation efficiency, crop water requirement, related evaporation and effective rainfall of the Vang Vieng Phi Irrigation Scheme during dry season (November- April) were considered for illustrative application of the proposed approach. Figure 2 shows the location of the Vang Vieng Phi Irrigation scheme in the Central of Lao PDR.

The Vang Vieng Phi Irrigation System has an estimated irrigation service area of 3,000 hectares during wet season and 1,070 hectares during the dry season. The main canal is good functional, but

Am. J. Engg. & Applied Sci., 2 (1): 133-138, 2009

secondary canals are poor functional, due to overflow. The tertiary canals were not completed of construction. The historical record of irrigated area in Van Vieng Phi from 2000-2007, the average irrigated area during the wet season is 1,086 hectares and 229.55 hectares during the dry season (rice and non-rice crops). It must be noted that the reported wet season irrigation area does not represent the total area planted during the wet season as the 3,000 hectares. The most areas are likely planted to rice during the wet season depending on rain for water supply.

The pumping station of Vang Vieng Phi irrigation scheme is a good condition. There are six pumps were installed in the pumping station. The capacity of each pump is working at 575 L sec^{-1}, pump efficiency by 85% and a stated peak water duty at the headwork of 1.84 L sec^{-1} ha^{-1} for dry season rice. Only 2 pumps have ever been put into operation at one time.

There is a reservoir that has a catchments area of 21 ha and maximum storage of 570,000 Mm^3 for storage water from pump station.

For water distribution practices, the cultivated areas are limited according to available water. Water delivery is limited to one zone at the same time with regular rotation. The irrigation scheme is divided into 5 zones for water distribution. Some areas are abandoned, especially the areas which are located far away from the canals. The overall irrigation efficiency of the Vang Vieng Phi Irrigation Scheme is 75.6%[11].

The proposed LP model is applied to find an optimum crop pattern of the Vang Vieng Phi Irrigation Scheme subject to restriction on water availability and land area. There are four land use types in the considered project such as rice, cucumber, maize and watermelon. Table 1 shows crop water requirement, crop yield, crop price and the calculated benefit rate of each crop. These data are used in the proposed model.

Table 1: Crop water requirement rate of each crop for seasonal cultivation[11]

Cultivation crops	Crop water requirement (m^3 ha^{-1})	Yield (kg ha^{-1})	Crop price (US\$ kg^{-1})	Benefit (US\$ ha^{-1})
Rice	14,195.70	4,690	0.30-0.45	389.8
Cucumber	5,719.86	8,375	0.15-0.25	278.7
Maize	4,995.00	5,725	0.10-0.20	257.3
Water melon	5,822.95	8,625	0.10-0.15	251.2

Note: 1 ha = 10,000m^2

The total area of scenario for several years is divided into 4 Water User Groups (WUG), 5 zones including: WUG 1 zone No. 1 of 185 ha, WUG 2 zone No. 2 of 245 ha, WUG 3 zone No. 3 of 250 ha, WUG 4 zone No. 4 and 5 of 350 ha.

In this study, the efficiency of the proposed LP model that can take into account of varied-utilized paddy fields is presented. For this reason, the unvaried-utilized character of the irrigation project is considered for comparing the case study.

Fig. 2: Location map of the Vang Vieng Phi irrigation scheme

RESULTS

These amounts of available water of one unit of pump, one unit of pump plus reservoir, two units of pump, two units of pump plus reservoir and three units of pump (4.15, 4.53, 8.30, 8.83 and 12.45 Mm^3) were applied to the proposed model for finding optimal crop pattern. Figure 3 showed the optimum crop pattern of the proposed LP model (varied-utilized) and unvaried-utilized character for the available water of one pump, one pump plus reservoir operated and two units pump respectively. They indicated that the fallow areas of the unvaried-utilized (800.41, 395.9 and 1070 ha) are larger than theirs areas of the proposed model (479.21, 353.94 and 250.9 ha). The obtained rice areas of proposed model bigger the obtained areas of the unvaried-utilized for all provide water.

Am. J. Engg. & Applied Sci., 2 (1): 133-138, 2009

Table 2 shows the net benefit of the scenario using the proposed LP model (varied-utilized characters of project) and the existing model (unvaried-utilized characters of project). The request area of 1,070 ha and available inflow from one unit of pump, one unit of pump plus reservoir, two units of pump, two units of pump plus reservoir and three units of pump were used to test the efficiency of the proposed model. The net benefit of the proposed LP model for the one unit of pump, one unit of pump plus reservoir, two units of pump, two units of pump plus reservoir and three units of pump are $2.42x10^5$, $2.63x10^5$, $4.17x10^5$, $4.17x10^5$ and $4.17x10^5$ US$ respectively. These net benefits of the proposed model are higher than theirs unvaried-utilized model. The sum of net benefit for varied-utilized case ($1.76x10^6$ US$) is larger than the sum of net benefit for unvaried-utilized case ($1.19x10^6$ US$).

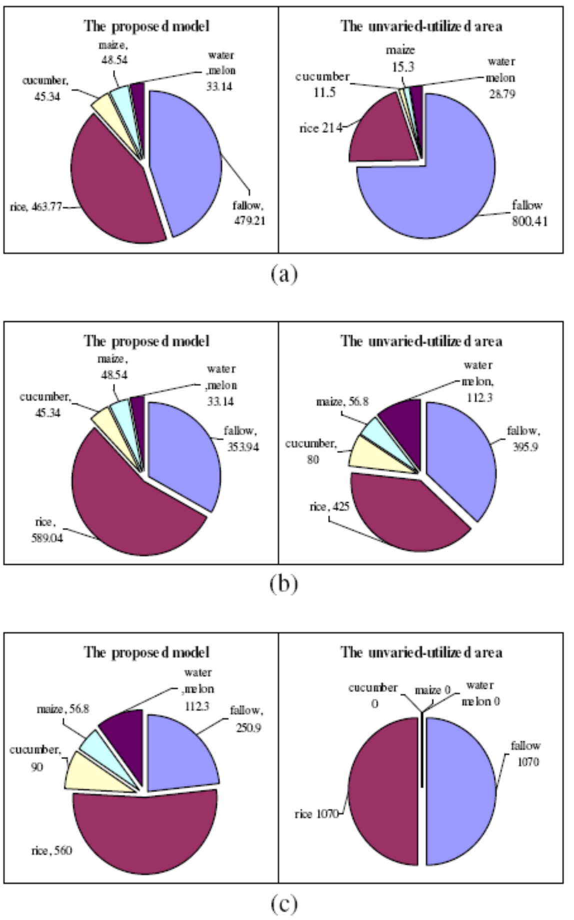

Fig. 3: Optimal crop pattern of the proposed and unvaried-utilized area

Table 2: Net benefit of the scenario using the Varied-utilized area (proposed model) and the Unvaried-utilized area

Request area (ha)	Pump operation	Available water supply (Mm^3)	Total benefit (US$) Varied-utilized	Unvaried-utilized
	1	4.15	$2.42 x10^5$	$9.78 x10^4$
	1+Reservoir	4.53	$2.63 x10^5$	$2.31 x10^5$
1,070	2	8.30	$4.17 x10^5$	$2.86 x10^5$
	2+Reservoir	8.83	$4.17 x10^5$	$2.86 x10^5$
	3	12.45	$4.17 x10^5$*	$2.86 x10^5$*
	Total		$1.76 x10^6$	$1.19x10^6$

*Not included fee of electricity

DISCUSSION

The larger fallow areas of the unvaried-utilize model than those areas of the proposed LP model indicates that the irrigated areas of proposed model huger than theirs unvaried-utilize model. This is because the proposed model considered varied-utilized soil type on allocating process. In addition, when having sufficient available water the proposed LP model provided the diversity of irrigated crops, while unvaried-utilized model provided rice area only (Fig. 3, c). This may be the benefit per irrigated unit of rice is the highest even high required water per unit area.

The net benefit of two units of pump, two units of pump plus reservoir and three units of pump are equal, because theirs available water supply are sufficient for allocating. The proposed model provided net benefit higher than the existing model for all cases. This indicated that variation of varied-utilized has a large impact on the optimal solution. For this reason, LP model with varied-utilized character of land area is appropriately for finding optimum crop pattern.

CONCLUSION

This study used a LP model by considering varied-utilized soil type on paddy fields to allocate the available land area under limited water supply. The irrigation project was divided into several sub-area based on suitable soil type for each crops for representing the varied-utilized characters of the large scenario in term of crop water requirement and crop yield. There are two main constraints of the proposed model, including water constraint and land area constraint. The proposed LP model provided the optimum crop pattern with net seasonal benefit which corresponding seasonal available water and required cultivation area.

Maximum net benefit comparison is done by taking the highest net benefit of the proposed LP model and highest net benefit of the existing model. It is found that the LP model obtained higher net benefit than the existing model considering unvaried-utilized character. The proposed LP model is appropriated to use for planning in the irrigation project.

ACKNOWLEDGEMENTS

The researchers would like to express the appreciation to the National Research Council of Thailand for financial support, the Mekong River Commission Secretariat (MRCS) and the Department of Irrigation (DOI) of Lao PDR for supporting data.

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Appendix E
Photos of Field Activities

Installation of ETc and Percolation Measurement

Measurement of Water Requirement for Fish Pond

ETo and Rainfall Measurement

Construction of Bamboo Bridge for all Measurement Points

ETc and Percolation Measurement at Up-Stream Command Area

ETc and Percolation Measurement at Down-Stream Command Area


Flow Measurement Point at Natural Stream


Measurement Point at Intake (Main Canal)


Flow Measurement Conducted at Main Canal


Flow Measurement Conducted at Main Canal


Gates at Rotation Point (N4)


Main Intake

Making Cross Section Area at Bamboo Bridge at Tertiary Canal

Observing Cash Crops (long been) Growing Nex to Paddy Nursery Plots

Paddy Nursery Plots

Land Preparation

Making Measurement Points

Vehicle Used for Field Observation


Meeting in Nam Houm Project **Meeting with WUAs**


Household interview **Field Observation**


Nam Houm reservoir **Paddy field**

Abbreviation:

CADA	:	Command Area Development Authority
DAFEO	:	District Agriculture and Forestry Extension Office
EdL	:	Electricite du Laos
EUT	:	Expected Utility Theory
FPUF	:	Factor Partial Utility Function
FAO	:	Foods and Agriculture Organization
FPI	:	Farmer Participation Index
IDS	:	Irrigation Diagnostic Study
IIEPF	:	Improvement of Irrigation Efficiency on Paddy Fields
ILO	:	International Labour Organization
IMT	:	Irrigation Management Transfer
ISF	:	Irrigation Service Fees
IWRM	:	Integrated Water Resource Management
DOI	:	Department of Irrigation
DP	:	Dynamic Programming
GA	:	Genetic Algorithm
GIS	:	Geographical Information System
GoL	:	Government of Laos
Lao PDR	:	Lao People's Democratic Republic
LNMC	:	Lao National Mekong Committee
LP	:	Linear Programming
MAF	:	Ministry of Agriculture and Forestry
MAUF	:	Multi-Attribute Utility Function
MAUT	:	Multi-Attribute Utility Theory
MOP	:	Multi-Objective Programming
MRCS	:	Mekong River Commission Secretariat
MSL	:	Mean Sea Level
NGO	:	Non-Government Organization
NIS	:	Nam Houm Irrigation System
PAFO	:	Provincial Agriculture and Forestry Office
PM	:	Prime Minister
PTD	:	Participatory Technology Development
RRR	:	Roles, Rules, Regulations
SPFS	:	Special Program for Food Security
STEA	:	Science, Technology and Environmental Agency
SWOT	:	Strengthen, Weak, Opportunity and Treat
UNCED	:	United Nations Conference on Environment and Development
UNCSD	:	United Nations Commission on Sustainable Development
VDF	:	Village development funds
WASAM	:	Water Algorithm Scheduling and Monitoring
WRCC	:	Water Resources Coordinating Committee
WSSAP	:	Water Sector Strategy and Action Plan
WUA	:	Water User Association
WUG	:	Water User Group
WUO	:	Water User Organization

Biodata

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