The Impact Assessment of Water Resource Management in Rainfed Area in the Upper Ping River Basin, Chiang Mai, Thailand

T. Yotapakdee and B. Havrland

***Abstract*—Water resources sustainability has crucial for the existence of farming system which is dependent on the cropping pattern practices. This paper concerns the studies of existing water resource management and determines factors affecting decision making of water resource management in rainfed area. In these cases, a multi criteria decision making model has been determined that aims at allocating efficient water and land resources to farms in the Upper Ping River basin in Chiang Mai, by optimizing a set of important socio-economic objectives which depend on sustainable agricultural and rural development. The solution was found by the using two analytical steps as follows: single objective optimization and compromise programming. In rainfed areas, the model cropping pattern advises farmers to grow the in-season rice, tobacco and longan. If the farmers follow the model cropping pattern even the gross margin increases insignificantly and water using increases slightly from the up to now existing water on farm consumption. The water resource management in rainfed areas the farmers store the scarce water in small reservoirs and water tanks on their farms for saving it for the dry season because the water on-farm security is an indispensable prerequisite in decide making upon the next year crop.**

***Index Terms*—Water resource management, cropping pattern, multi criteria decision making, farming system.**

I. Introduction

In Thailand, the yearly demand for water is about 53 billion cubic meters. Out of this volume, almost 71 percent is allocated for agriculture, 5 percent for domestic consumption and the rest is for the use in industries [1]. The annual demand for water is estimated at about 70 billion cubic meters annually in the next 10 years [2]. Thailand has been divided into 25 river basins. The average annual countrywide rainfall is about 1,700 mm. The total volume of water from rainfall in all river basins in Thailand is estimated at 800 billion m3, 75 percent of which (about 600 billion m3) is lost through evaporation, and infiltration; the remaining 25 percent or 200,000 billion m3 constitutes the runoff that flows in rivers and streams [1]. As a result of water scarcity, competition for water thus exists between regions, between different sectors, and even between upstream and downstream users in the same catchments and river basins.

In the Upper Ping River basin which covers a catchment area of around 25,370 km2 in the provinces of Chiang Mai and Lamphun, northern Thailand [3]. The Upper Ping River basin can be separated into 14 sub-basins and mostly covered by forest and steep mountains, which form a line from the northern to the southern parts of the basin [4]. The average annual runoff and rainfall of the catchment are around 6,815 million m3 and 1,174.1 mm, respectively [5]. Water requirement includes domestic consumption at 75.26 million m3, ecological balance 457.27 million m3, irrigation or agriculture 2.4282 billion m3 and hydropower 3.623 billion m3 [1].

The lack of water in agricultural sector pushes farmers to adapt themselves as best as they can to a declining and fluctuating water supply. Several water management strategies at farm level have been applied to prevent water shortage in their farms such as investment in pumping devices and water storage and investment in water distribution technology at farm level. This article reports on a study about existing water resource management in rainfed area in order to get better understanding of the current water use and management in Chiang Mai Thailand. It is expected that the research conducted in the Upper Ping River basin in Chiang Mai Thailand will identify a potential of water resources under sustainability development as well as assess the impact of future development on farm activities and farmers' livelihood.

II. Materials and Methods

A. Overview of Applied Data Set

The indicators are introduced as accounting equations in the simulation models of which indicators are from the vector of crop plans chosen by agricultural producers. The indicators are economic, social and environment. The economic indicator is total gross margin while the social indicator is the total labour because the degree of employment explains the social importance in the agricultural sector and distribution of this income in each area. The environment indicator is water use which is quantified in terms of crop water requirements on farms.

B. Goal Programming Model

A multi criteria Mathematical Programming model has been developed to support the spatial development planning process. The model achieves the optimum farm plan in the area combining different criteria to a utility function under a set of constraints concerning different categories of land, labour, available capital, etc.

1) Model specification

a) Variables

Each farmer has a set of variables Xi (crops). These are the decision variables that can assume any value belonging

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to the feasible set. The economic values of the crops resulted from the agricultural indicators form the survey data.

b) Objectives

Four objectives have been specified for the case illustrated here:

i) maximization of gross margin to farmers, operators and family labour;
ii) maximization of hired labour employment;
iii) minimization of risk from price alternations;
iv) minimization of risk from yield alternations.

2) Formulation of multi objective problem

Objective 1: Maximization of gross margin to farmers, operators and family labour (FI)

The gross margin to farmers, operators and family labour at different crops is obtained by subtracting total variable costs (hired labour cost, fertilizers, pesticides, irrigation and other costs) from gross revenue [6].

$$MaxFI = \sum (R_i - C_i) X_i \quad , i = 1, 2, \ldots, n \qquad (1)$$

where: FI .. farm income of crop
R_i .. gross margin from crop *i*;
C_i .. total variable costs incurred in the production of crop *i*;
X_i .. the area allocated to production of crop *i*;
i .. the crop index.

Objective 2: Maximization of hired labour employment

The intensity of production as well as absence of mechanical means to perform most of the operations involved in vegetable production results in a large share of hired labour cost to total variable cost [6].

$$MaxHL_i = \sum HL_i = \sum (TL_i - FL_i) X_i \quad ,i = 1, 2,..,n \qquad (2)$$

where: HL_i .. hired labour requirement of crop *i*;
TL_i .. total labour requirement of crop *i*;
FL_i .. family labour available for crop *i*;
X_i .. the area allocated to production of crop *i*;
i .. the crop index.

Objective 3 and 4: Minimization of risks

An economically feasible production plan must pose a minimum risk to farmers. The minimum risk is due to variable weather conditions, insect, pests and diseases infestations and changes in prices and other market conditions that create conditions of higher variability in farm incomes realized by farmers through their production [7]. The total income variance of incomes derived in the production of crop i with the gross margin, Ri, can be formulated as a quadratic formula given by:

$$V(I) = \sum \sum \sigma_{ij} X_i X_j , \quad i,j = 1, 2, \ldots, n \qquad (3)$$

where: V(I)…total income variance
σ_{ij} ... Variance-covariance matrix of net income derived from the production of crop *i*;
X_i .. the column vector of the level of production activity;
X_j .. the row vector of the level of production activity;
i ... the crop index in the column vector;
j ... the crop index in the row vector.

Minimization of total income variance can then be expressed as:

$$MinV \; (I) = Min \sum \sum \sigma_{ij} X_i X_j \quad ,i,j=1,2,...,n \qquad (4)$$

Two sources of the minimum risk include: price induced by the minimum risk and yield induced by the minimum risk on the income. The price induced by the minimum risk is associated with the availability of the product in the market that is observed from year to year. The yield induced by the minimum risk is associated with the stability of yield of the crops from year to year. The set of objective functions is constrained by availability of resources of vegetable farmers. These resources include: land, capital, labour, fertilizers, pesticides and irrigation water.

3) Constraints imposed on the model include as follows:

1) Land: sum of all crop areas is equal to the total available area. The total land used for different crops at any time cannot exceed the total available land. The land allocated to a crop remains unchanged from the time of sowing to time of harvesting [8].
2) Labour: amount of family working labour is used as the upper limit of family labour constraints. The family working labour is assumed to be equal in each month. Hired labour is assumed to be unlimitedly available.
3) Capital: sum of all crops requiring capital is equal to the total available capital, earned incomes through sales of crops and available one unit of loan in each season.
4) Irrigation water: total water use in the irrigation areas should not exceed the total allocation in a given month [9].

$$TWREQ = \sum_c (X_c WREQ_{cm}), \quad m=1,..,12 \qquad (5)$$

where: TWREQ .. total water requirements of all crops per month;
WREQ .. each crop of water requirements per month;
X_c .. the area allocated to production of crop *c*;
c .. the crop index;
m .. months of the year.

However, the crop water requirements per month WREQ (c,m) may be estimated as a function of the crop coefficient, crop growth duration, evapo-transpiration and rainfall using climatic data or based on water balance techniques.

$$\sum_c (X_{(c)} WREQ_{(c,m)}) \le Allocation\ (m), \quad m=1,\ldots,12 \qquad (6)$$

The water requirements in this paper are assumed as the excess from evapo-transpiration over rainfall. Requirements for leaching of salts or pre-irrigation are not considered. The fraction of growth period in a given month for a given crop (d_ratio(c,m)) is given by:

$$d\_ratio(c,m) = G\_duration(c, m)/days(m) \qquad (7)$$

where: *G_duration(c,m)* .. growth duration of crop *c* in one month *m*;
days(m) .. number of days in one month *m*.

The crop water requirements are evaluated as follows:

$$WREQ(c,m)=k_a(c,m)d\_ratio\times ET(m)-d\_ratio(c,m)Rain(m) \quad (8)$$

where: $k_a(c,m)$ .. crop coefficient of crop c in month m and $ET(m)$;

$Rain(m)$ .. evapo-transpiration and rainfall in one month m.

5) Commodity balance: crop products can be sold in the market or consumed by the family.

4) Activities included in the model are as follows:

1) Farm activities: farming activities for each farming system are more or less the same. The crop activities consist of rice, other annual crops and vegetables [10].
2) Labour activities: family labour can be used within the farm to fulfil own requirements and for off-farm activities, too. The family labour for household activities is also required. Hired labour is allowed in order to increase labour supply [11].
3) Credit activities: two forms of credit are available in the model, formal and informal credit. The short term (one year) formal credit is allowed for the household. The informal credit comes from traders or other informal institutes and the long term (ten year) formal credit is allowed for the household from formal credit.
4) Water activities: water required for crop production is obtained from the available surface water resource which is available in each month [8].
5) Market: yield of all crops can be sold in the market at which the farmers can get market price in the period 2010/2011. The model put an average price of cultivation of these crops.

III. Result

The goal of the research explained existing water resource management in rainfed area in Upper Ping River basin. Water resource management in rainfed area, almost of farmers cultivating annual crops; the farmers were using crops undemanding the water. The farmers stored the lacking water in small reservoirs and water tanks on their farm for saving water for the dry season. Such water on farm storage is useful for their decision-making on cultivation practices in the next year.

There is the water resource management in rainfed area at 2 types. The first private management, farmers do not want to share water with other farmers. They can invest on their farm by themselves such as water tank, small reservoir etc. but the size of water saving depends on their capital. The second relative management, farmers in one zone is the relatives who have the farm nearby together which they can get the trust and confident together in their farms zone. It is easy to allocate, manage and develop by talking for solving the problem or invest the water security on their farm. The size of water saving have the bigger than private management because the farmers amass money for building the security water system on centre for sharing to their farm.

In rainfed areas there is a potential for growing 10 crops (the in-season rice, long bean, marigold, maize, sweet corn, tobacco, galangal, lemon grass, banana and perennial crop - longan); all this in the existing crop pattern. However, the model cropping pattern advises those farmers to grow the in-season rice (0.07 ha), tobacco (0.43 ha) and longan (0.57 ha), only. If the farmers follow the model cropping pattern even the gross margin increases insignificantly by 764,046 baht (see Table I) and water using increases slightly from the existing on farm water consumption (101,601 m^3) up to 680,869 m^3 as linked to the model cropping pattern in Fig. 1. The sensitivity analysis was conducted by use of the longan price at rainfed area at the use of suitable cropping pattern given by the model. The result of sensitivity analysis did not change from the model cropping pattern, therefore the result still uses the suitable cropping pattern given by model

TABLE I: Comparison of Existing Crops and Suitable Crops Proposed by The Model Cropping Pattern on Rainfed Areas

Crops	Existing crops (ha)	Model cropping pattern (ha)
In season-rice	0.91	0.07
Long bean	0.28	-
Marigold	0.28	-
Maize	0.67	-
Sweet corn	0.64	-
Tobacco	1.08	0.43
Galangal	0.8	-
Lemon grass	0.16	-
Banana	0.93	-
longan	0.97	0.57
Gross margin (baht)	113,162.6	764,046

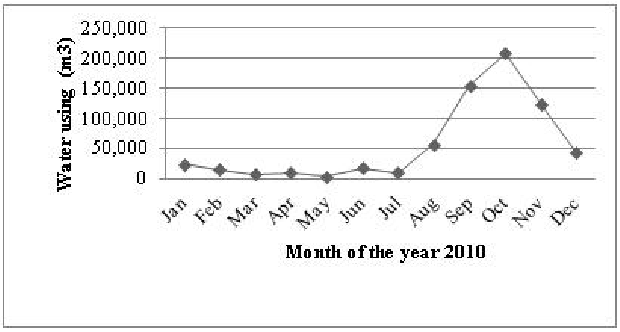

Fig. 1. Water using in rainfed area by model cropping pattern year 2010/2011.

The factors affecting decision-making about water use and management in rainfed are is the first factor affecting the decision-making process on crop cultivation depends on the price. If farmers foresee increased price of some crops they will cultivate it on larger areas than the year before. However, the price support from government is also important to influence the farmers´ decision.

The second factor is the cost of cultivation of each crop. It is because the farmers decide to cultivate crops at lowest possible costs but under the condition they would get the highest farm incomes.

The last factor to be assumed by farmers is water supply capacity. The farmers have to know the inflow potential for each year before the crop planting season. If they know they will have less water they decide to grow less water demanding crops. As the consequence of the lack of water the farm economy is always disturbed and the farmers lose incomes.

The development potentials of water resource management under sustainable conditions in rainfed area are the farmers are aware of water scarcity on farms for the next generations. The development potential depends on the conservation and protection of forest resources by the local community.

IV. Conclusion

The water resource management in rainfed areas the farmers store the scarce water in small reservoirs and water tanks on their farms for saving it for the dry season because the water on farm security is an indispensable prerequisite in decide-making upon the next year crop. The multi-objective model advises those farmers to grow the in-season rice, tobacco and longan.

The factor affecting decision-making on water use and management in rainfed area are price, costs and water supply capacity. If the farmers see a price increase or a price support of some crops by the government they will cultivate its more area than the year before. The farmers also prefer to grow low cost crops but suppose to get high on farm incomes. They require to know a future water potential inflow before the crop planting season. If they have prospects to get less water they are going to grow less water demanding crops.

The development potential of water resource management under sustainable conditions in each farming system is different because the farmers are aware of water scarcity on farms for the next generations. The development potential consists in conservation of forest resources by the local community especially in rainfed areas. The farmers have the sustained development in the water users´ group to be strong in brain storming for getting knowledge and develop their fields.

It can be recommended to use the cropping patterns proposed by multi-function model on farms in Ping watershed. The model is consistent with each farming system where there are differences in risk and uncertainty. Because the risk and uncertainty come from weather condition, nature resources and flexible of market these factors must be considered as variables which cannot be controlled by farmers themselves. The above model processes these factors and produces management advice which is, according to our survey, acceptable by the farmers for their better operational and economic (including water consumption) parameters.

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