Modelling and Simulation of Water Resources Management: A Case Study of Northern Thailand

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Abstract

Assessment of future impact can be done by different methods especially programming models. This study is to analyse future impact of different strategies and policies in water resources management and irrigation systems on the living standard of farm families, Phayao province, Northern Thailand. To be realistic, strategies are based on problems facing the farmers and farmers' requirements. Two strategies are, namely, increasing irrigation water availability, and improving technical efficiency of irrigation management systems. A family model is applied and includes farm, household and external relations and maximizes family income in the objective function. A static linear programming model interpreted in a comparative static analysis is used to investigate various options to improve the use of irrigation water and their impact on farm-family income. The data are based on a field survey carried out in 1994/95. Regarding diversity of irrigation systems in the area, they are classified into four groups. The models are applied based on average families. The family reflected in the model is to a certain extent a "mean average parameter family" and not an existing family with the smallest standard deviation of the sum of parameters. Results of the future impact analysis provide recommendation for the irrigation authorities to improve their service and ultimately the living standard of the farm family. The result indicates that increasing irrigation water availability based on farmers' investment will be a constraint in future strategies. If the investment allows introducing some dry season crops, the farmers' investment in increasing irrigation water availability will turn out to be profitable for the farm families in all groups. Increasing technical efficiency by improving water distribution systems has a predominant impact on farming development and the regional supply of agricultural goods. This offers the opportunity to introduce water charges combined with the increasing water distribution efficiency.

Introduction

It is generally agreed that Thailand has tremendous problems in water resource development, especially due to climatic changes, increased water demand, inefficient use of water, limited water storage capacity and distribution systems, watershed management deficits, water quality and water conflicts (Christensen and Boon-Long, 1994). Moreover, the existing water resources are generally plagued by performance far below their expected potential, for example, irrigation efficiency in Thailand lies in the 15-30% range. Northern Thailand is quite outstanding in this regard. Available evidence shows that water is already scarce and unreliable in most parts of Thailand but it is particularly pronounced in the northern part. The widespread scarcity and unreliability of water and aggravated water resources in Northern Thailand demand integrated water resource planning and management. This study examines the future impact of different strategies and policies in water resources management and irrigation systems on the living standard of the farm families with the aim to finding and discussing potential solutions.

Study area

Two criteria are used to select the study area, namely, agro-ecological condition and irrigation projects diversity. The study area is the upper part of Mae Ing river basin is located in Muang and Mae Chai districts, Phayao Province, Northern Thailand (Figure 1). It extends approximately from 19° to 19°35′ north latitude and from 99°40′ to 99°55′ east longitude. The study area covers approximately 1,103 km^2.

Methodology

In irrigation management, the impact analyses of technical, managerial and organizational improvements considers resource availability, mobility and potential increase; investment in resource improvement; processes of production, processing, marketing, storage and credit supply to use the resources available; and the objective of those making decisions in irrigation development and management (Doppler, 1989). Assessment of the future impact can be done by different methods especially programming models. There is a list of studies that have been done in this frame work, for example, Doppler (1976), Wightman (1990), Salman (1994) and Adam (1996).

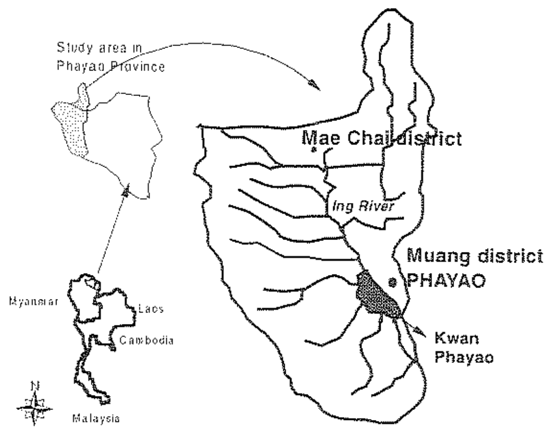

Figure 1 Map shows the upper part of Mae Ing river basin, Phayao Province, Northern Thailand

Regarding to the problems facing the farmers and the farmers' requirement related to water resource use (by conducting farm survey), two strategies are selected in order to measure the impact on the living standard of the farm families. Strategy one is concerned with increasing irrigation water availability. The second strategy is to increase the technical efficiency of the irrigation management systems.

In the study, a family model is applied which includes the farm, the household and the external relations and maximizes the family income in the objective function. A static linear programming model interpreted in a comparative static analysis is used to investigate various options to improve the use of irrigation water and their impact on farm, off-farm and family income. The impact is determined by the results of model applications under the "with-and-without" development in the future. The difference between future development with improvement strategies and without these strategies is the impact of the strategies tested (Figure 2).

The static linear programming model used in this analysis can be mathematically presented as follows:

Equation 1 $$\text{Max } Z = \sum_{i=1}^{n} P_i X_i - C_i X_i$$

Subject to $$\sum_{j=1}^{m} X_i a_{ij} = b_j \quad \text{all } j = 1 \text{ to } m$$

and $$X_i \geq 0 \quad \text{all } i = 1 \text{ to } n$$

Where;

Z = the objective function to be maximized family income

X_i = activity i of farm, household, external relations

n = number of possible activities

C_i = cost per unit of the i input activity

P_i = sale price per unit of the i output or service

a_{ij} = the input-output coefficient or the quantity of the j resource required to produce one unit of i activity

m = the number of resources

b_j = the amount of the j resource available

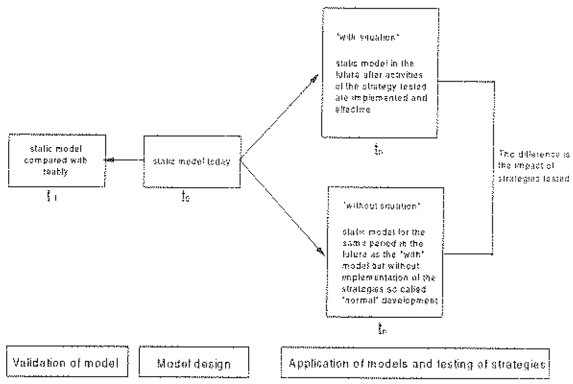

Figure 2 Principles design and application of models

The model maximizes the values in the objective function comprises the family income and optimizes resource allocation for the various activities. Four basic family-household models are constructed to represent the four irrigation management groups in the study area namely: state managed medium reservoir group; farmer association managed small reservoir group; farmer association managed weir group and farmers' group managed non-structured weir group. The data are based on a field survey carried out in 1994/95. The coefficients reflect the input-out relations observed in each system.

The farm-household-family models applied here for the different irrigation management systems have basically the same structure. They differ only with respect to structural differences in the irrigation systems analysed. The models are applied based on average families. This means all parameters used in the model are data from a certain group irrigation system in the survey and represent mean averages. The family reflected in the model is to a certain extent a "mean average parameter family" and not an existing family with the smallest standard deviation of the sum of parameters.

Validation of the models

The determination of the quality of the models is measured in the validation of the structure of the basic model and matrix. The criteria for this are the closeness of model results to reality when the model is applied in the year of the data collection.

Due to the complexity of the farming systems in reality and the relatively limited information and simplicity of models may not precisely represent reality. In addition, in optimizing models perfect knowledge and information is assumed, so that the optimum is reached immediately. In reality, farmers may react in the following year after they get new information. Risk behavior may also influence farmers not to reach the optimal point of solutions. Due to this, farmers' decisions may show a time lack in the optimal path of development, while models produce the optimum immediately. The results of these models are, therefore, just an indicator of reality because this simplified structure cannot cover all the actions of the complex systems (Praneetvatakul, 1996).

In this study, criteria for validation of the models consist of farm and family income; use of family owned and external resources; and types and extent of activities in crop and livestock production. The results of the basic linear programming models show that the farm incomes were higher than the farm income from the field survey in all the groups (Table 1). On the other hand, the model results show lower off-farm income figures compared to the off-farm income in reality. This was because the remittance was not included in the model. Regarding the family income, the model results indicate the differences from the family practices. In all the groups, it can be seen that the differences ranged from decreased by 6% to increased by 18%.

The differences in the use of family and external resources can be explained that in reality the farmers may react depending on the updated information. Risk behavior might in this case influence the farmers not to reach the optimal point of solutions. Empirical studies have demonstrated that farmers typically behave in risk-averse ways (Binswanger, 1980; Dillon and Scandizzo, 1978 cited by Hazell and Norton, 1986). Farmers often prefer farm plans that provide a satisfactory level of security even if this means sacrificing income on average. Due to this, there is a gap between the model results and the family practices.

Table 1 Comparing family income and farming activities as results from basic models and with family practices, Phayao Province, Northern Thailand 1994/95

	SM-MRS[1/]		FAM-SRS[1/]		FAM-WS[1/]		FGM-NS[1/]	
Income(baht/family/year)/ Farm activities	family practice	basic model	family practice	basic model	family practice	basic model	family practice	basic model
Farm income	15,538	16,900	15,377	18,474	12,937	21,519	7,175	11,323
Off-farm income	13,702	11,840	15,936	10,920	22,220	20,012	13,313	11,938
Family income	29,240	28,740	31,313	29,394	35,157	41,532	20,488	23,261
Irrigated area ws[2/](rai)	9.30	8.83	6.84	13.74	7.86	12.81	5.50	3.56
Irrigated area ds[2/](rai)	0.00	3.94	0.54	2.03	0.37	1.65	0.08	1.23
Non-irrigated area(rai)	1.10	3.34	0.21	0.00	0.03	0.00	3.90	3.36
Renting-in land(rai)	2.14	2.17	2.50	6.39	2.27	5.08	1.24	0.31
Cropping intensity	1.02	1.12	1.03	0.97	1.03	1.07	1.17	0.86

Note: 1/ SM-MRS is the state managed medium reservoir; FAM-SRS is the farmer association managed small reservoir FAM-WS is the farmer association managed weir; FGM-NS is the farmers' group managed non-structured weir

2/ ws is the wet season, ds is the dry season

The model results more or less approximate reality in the four groups being analysed. This, therefore, means that the models can be used for testing the future impacts of improved conditions on the farm family.

Future impact of selected strategies at the family level

The family models were then applied to impact analyses by measuring the impact on farm and family income, and farming activities. These strategies were tested in four different irrigation management systems. Under these conditions, the differentiation of this part will follow strictly the definition of the strategies.

The impact of increasing irrigation water availability

Model assumption:

- Investment in water storage capacity which increases water availability at the farm level by 25%, and this is defined as an increase in the dry seasons by 258 m^3/rai, in the state managed group, 223 m^3/rai in the farmer association managed small reservoir group, 163 m^3/rai in the farmer association managed weir group and 100 m^3/rai in the farmers' group managed non-structured weir group. As a consequence, the irrigated area in the dry season can reach at 30% of the command area in the wet season.

- Regarding investment cost in removing the sedimentation in reservoir or weir, including establishing an additional canal and improving canal (lining), the costs are estimated at 66, 81, 143 and 163 baht/rai in the state managed, farmer association managed small reservoir, farmer association managed weir and farmers' group managed non-structured weir groups respectively. Additionally, future annual running costs are 3 baht/rai for all the groups.
- In order to be realistic, with and without introducing the dry season crops are tested under this condition.

a) The impact of farmers' decisions on investment in water availability: Investment capital will only come from the family resources or private credit.

The family models were applied to determine future development with and without farmers' investment in improving irrigation water availability and show the impact of this on farm and family income (Table 2). Farm income was slightly lower than in the basic models in all the groups. The lower farm income values were expected because the expenditures of the family were higher, including some changes in use of family owned and external resources. The model results had no effect on the off-farm income. This shows that the off-farm income in all the groups is not closely related to the farm activities. As relates to the family income, evidently an increase in expenditure to improve water availability paid by the farmers themselves had a negative effect on the family income. The family incomes were lower than the basic model results by between <1% to 2%.

As soon as it is possible to introduce some dry season crops in the production in the farm, the impact of investment by the farmers themselves in increasing irrigation water availability became profitable in all the groups (Table 2).

The improving irrigation water availability by the farmers' investment increased the use of the families own resources, such as the irrigated area in the dry season. This was under the assumption that improving irrigation water availability increases the irrigated area in the dry season. Due to this, the farms reduce the use of the external land resource (rented land) in the dry season in all the cases. Family labor was not adequate for the farming activities, therefore hired labor was needed in the peak period. There was only slightly change in borrowing money. This implies that the families are able to improve the water availability by their own resources (for this investment) without increasing the degree of dependencies. However, these investments reduce their farm and family income as mentioned earlier. Improving irrigation water availability with and without introduction of the dry season crops leads to an increasing use of land, implied by increasing in the CI.

b) The impact of policy decisions in financial improvement in water availability: Investment is subsidized by the public by offering loans at no interest rate. Therefore, the investment cost is not included in the model.

The model results show that the farm incomes were higher than in the basic models in all the groups (Table 2). As was the case of farmer financed improvement in water availability, subsidies do not affect the level of the off-farm income in all the groups. Subsidies in increasing water availability had a positive effect on the level of family income, ranging from <1% to 5%.

As soon as the dry season crops are introduced into the model under the increasing water availability through subsidies, the positively impact of this on farm and family income was higher than the model results of increasing water availability without introducing the dry season crops.

The increasing irrigation water availability by the subsidies increased the use of family owned land resource. By contrast, this impact reduced the use of the external land resource (rented land). Family labor was not adequate for the farming activities, therefore hired labor was needed in the peak period.

The impact of the increasing water availability through subsidies on the farming activities (crop and livestock) was more or less the same as through the farmers' investment.

Table 2 Impact of investment in increasing water availability on the family income and crop activities in Phayao Province, Northern Thailand, 1994/95

Income(baht/family/year)/ Farm activities	SM-MRS[1/] basic model	SM-MRS[1/] invest-ment	FAM-SRS[1/] basic model	FAM-SRS[1/] invest-ment	FAM-WS[1/] basic model	FAM-WS[1/] invest-ment	FGM-NS[1/] basic model	FGM-NS[1/] invest-ment
Farmers' investment								
Without dry season crops								
Farm income	16,900	16,612	18,474	17,792	21,519	21,433	11,323	10,861
Off-farm income	11,840	11,840	10,920	10,920	20,012	20,012	11,938	11,938
Family income	28,740	28,453	29,394	28,712	41,532	41,445	23,261	22,799
Irrigated area ws[2/](rai)	8.83	8.83	13.74	13.24	12.81	8.80	3.56	3.56
Irrigated area ds[2/](rai)	3.94	3.94	2.03	2.03	1.65	2.35	1.23	1.84
Non-irrigated area(rai)	3.34	3.34	0.00	0.00	0.00	0.00	3.36	3.36
Cropping intensity	1.12	1.20	0.97	1.00	1.07	1.19	0.86	0.92
With dry season crops								
Farm income	16,900	18,934	18,474	23,636	21,519	22,322	11,323	17,444
Off-farm income	11,840	11,840	10,920	10,920	20,012	20,012	11,938	11,750
Family income	28,740	30,775	29,394	34,556	41,532	42,335	23,261	29,194
Irrigated area ws[2/](rai)	8.83	8.83	13.74	12.57	12.81	8.80	3.56	7.31
Irrigated area ds[2/](rai)	3.94	6.79	2.03	4.69	1.65	2.74	1.23	1.84
Non-irrigated area(rai)	3.34	3.34	0.00	2.01	0.00	0.00	3.36	2.69
Cropping intensity	1.12	1.16	0.97	1.14	1.07	1.18	0.86	1.14
Subsidy								
Wihtout dry season crops								
Farm income	16,900	17,437	18,474	18,614	21,519	21,933	11,323	12,376
Off-farm income	11,840	11,840	10,920	10,920	20,012	20,012	11,938	11,938
Family income	28,740	29,277	29,394	29,534	41,532	41,945	23,261	24,315
Irrigated area ws[2/](rai)	8.83	8.83	13.74	13.74	12.81	8.80	3.56	3.56
Irrigated area ds[2/](rai)	3.94	3.94	2.03	2.03	1.65	2.35	1.23	1.84
Non-irrigated area(rai)	3.34	3.34	0.00	0.00	0.00	0.00	3.36	3.36
Cropping intensity	1.12	1.20	0.97	1.00	1.07	1.19	0.86	0.92
With dry season crops								
Farm income	16,900	19,759	18,474	24,444	21,519	22,838	11,323	18,539
Off-farm income	11,840	11,840	10,920	10,920	20,012	20,012	11,938	11,746
Family income	28,740	31,599	29,394	35,364	41,532	42,850	23,261	30,285
Irrigated area ws[2/](rai)	8.83	8.83	13.74	12.57	12.81	8.80	3.56	6.14
Irrigated area ds[2/](rai)	3.94	6.79	2.03	4.69	1.65	2.73	1.23	1.84
Non-irrigated area(rai)	3.34	3.34	0.00	2.01	0.00	0.00	3.36	2.98
Cropping intensity	1.12	1.16	0.97	1.14	1.07	1.18	0.86	1.19

Note: [1/] SM-MRS is the state managed medium reservoir; FAM-SRS is the farmer association managed small reservoir FAM-WS is the farmer association managed weir; FGM-NS is the farmers' group managed non-structured weir
[2/] ws is the wet season; ds is the dry season

The impact of increasing technical efficiency by improving water distribution systems

Model assumption:

- The existing water distribution system was not efficient, therefore, the system could operate with less water (80 to 90%).
- The increase technical efficiency in organizations of irrigation projects is defined as the improvement of the water distribution.
- This improvement leads to increased crop productivity because adequate water is sent in the right time.

Improving water distribution efficiency increases the efficiency of farm resources and in turn farm income. This impact increased farm income, ranging from 24% to 61% (Table 3). Regarding off-farm income, it is to be noted that there was no impact on the off-farm income for all the groups with improving water distribution efficiency. Exception was found in the farmers' group managed non-structured weir group, where there was a marginal decrease of 6% of the off-farm income. The improvement in water distribution efficiency led to an increase in the family income, ranging from 9% to 39%.

The improvement in water distribution efficiency increased use of family owned and external resources. Improving the water distribution efficiency increased the need for credit that was mainly obtained from the formal institution in all the groups.

An assessment of the impact of an improvement in the water distribution efficiency in the systems reveals that there was a positive impact on farming activities. The irrigated area increased in the wet season in all the groups, meaning that more area was put into rice cultivation through renting land and use of fallow land.

Table 3 Impact of improvement of water distribution efficiency on the family income and crop activities in Phayao Province, Northern Thailand, 1994/95

	SM-MRS[1/]		FAM-SRS[1/]		FAM-WS[1/]		FGM-NS[1/]	
Income (baht/family/year)/ Farm activities	basic model	improve distri.[3/]	basic model	improve distri.	basic model	improve distri.	basic model	improve distri.
Farm income	16,900	22,857	18,474	29,822	21,519	32,024	11,323	14,040
Off-farm income	11,840	11,840	10,920	10,920	20,012	20,012	11,938	11,278
Family income	28,740	34,697	29,394	40,742	41,532	52,036	23,261	25,319
Irrigated area ws[2/](rai)	8.83	14.48	13.74	15.64	12.81	15.64	3.56	4.55
Irrigated area ds[2/](rai)	3.94	6.86	2.03	2.83	1.65	3.13	1.23	1.23
Non-irrigated area(rai)	3.34	3.34	0.00	0.00	0.00	0.00	3.36	3.05
Cropping intensity	1.12	1.08	0.97	0.98	1.07	1.06	0.86	0.96

Note: 1/ SM-MRS is the state managed medium reservoir; FAM-SRS is the farmer association managed small reservoir FAM-WS is the farmer association managed weir; FGM-NS is the farmers' group managed non-structured weir
2/ ws is the wet season; ds is the dry season 3/ Improvement of water distribution efficiency

Conclusions

Results of the future impact analysis provide recommendation for the irrigation authorities to improve their service and ultimately the living standard of the farm family. Currently and in the future, farmers' investment in increasing the irrigation water availability, by improving the water storage capacity and the canal system, is not economical in all irrigation projects. However, if the investment allows introducing some dry season crops, the farmers' investment in increasing irrigation water availability will turn out to be profitable for the farm families. As expected, any public subsidies to increase irrigation water availability through improving the water storage capacity and the canal system had positive effects on the farm and family income. The improvement of water distribution efficiency leads to increases in the crop productivity because adequate water is sent in the right time. On account of higher yields, land use efficiency and income were increased. Increasing water distribution efficiency had a predominant impact on farming development and on the regional supply of agricultural goods. This offers the opportunity to introduce water charges combined with the increasing water distribution efficiency.

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