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A Systematic Approach to Assess Highland Resource Management Options in Northern Thailand

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ABSTRACT

An integrated modeling system has been developed to address problems of resource management in the highland of northern Thailand based on a multidisciplinary approach. This paper first discusses the framework of an integrated economic-hydrological-crop production model, then its validation in Mae Uam sub-catchment in Northern Thailand.

Keywords: highland resource assessment, integrated modeling.

1. INTRODUCTION

Drastic deforestation and resource depletion in Thailand has long been a recognized problem, drawing much attention and activities from both government and non-government organizations. The common objective of these activities is an attempt to balance the major roles of the highlands in terms of environmental protective functions, especially maintaining watershed services, and productive functions, including agricultural production and forest products for the traditional highland communities. As the two major roles are often incompatible, conflicts of highland resource uses are expected to grow more intense. The key challenge facing the decision-makers is the capability to plan for sustainable uses of the highland resources while maximizing the long-term net social benefits.

The nature of natural resource management in the highlands calls for an integrative approach due to the complex interaction between human beings and natural resources. The Integrated Water Resource Assessment and Management Project (IWRAM), which is a joint research program of the Australian National University in Australia and various agencies in Thailand, is among the very first that have attempted to address such problems. In this project, two integrated models are developed with slightly different approaches [1]. This paper will discuss one of those two models which emphasizes linking the biophysical constraints to socio-economic conditions. The outputs on economic environmental trade-off will assist the stakeholders to assess various management options. The model also allows users to build limited scenarios such as external price shock, legal or institutional change into the decision process which will enable them to explore the likely impact of those scenarios on resource use patterns. Such information should prove valuable to resource planners/managers or even policy makers.

2. MODELING FRAMEWORK

The framework of this integrated model consists of three levels of entities that are linked together. The three entities are Resource Management unit (RMU), Node and Catchment.

2.1. Resource Management Unit (RMU)

Farms or households are classified into different types, called resource management units or RMU [2]. In the IWRAM Project analysis, we assume that the two main biophysical factors that influence the types of crop selected by each household are the topography of arable land (i.e., upland or lowland) and access to irrigation water (i.e., rainfed or irrigated). Therefore we can typically classify farm households into 15 RMU types. As farm households in each RMU receive similar major inputs and face the same socio-economic conditions, we assume that the decisions on resource allocation would be homogeneous and can be modelled by a representative farm. The decisions at the farm level can then be aggregated up to the node level.

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2.2. Node

The term node is defined, conceptually, as 'water balance unit.' Its implication depends much on the aspect from which a node is looked at. From the hydrological aspect, a node represents a sub-catchment and a network of nodes forms a catchment. Each node therefore has a physical domain, which has to conform to that of the sub-catchment it represents. Within this physical domain exist other biophysical attributes such as drainage pattern, slope, aspect, soil types, climate parameters etc. These biophysical attributes constitute a process, which determines the amount of water that flows in and out of the node.

From the socio-economic aspect, the characteristics of farm households, alternative land use options, farmers' priorities and constraints characterized by RMU types may differ from node to node. The different set of socio-economic conditions would influence the decisions as to how they should manage their available resources (land and water in particular) to their optimum level of production.

From the modeling aspect, a node plays a major role in the whole decision support system. A node is the level at which all modeling engines are activated and linked together. The main outputs from the modeling process, although initiated at farm or plot level, reflect the interaction between human and resource availability at the node level.

2.3. Catchment

As mentioned in 2.2, a catchment area is split into nodes. Nodes are tied together by a network of streams. Therefore land uses and irrigation consumption which occurs on upstream node(s) certainly affects water availability at downstream node(s). Modeling at a catchment level aims to identify possible land and water management options on a larger scale, where the available water resource is the consequence of activities occurring upstream.

3. MODELING ENGINES

In order to properly address resource management problems, biophysical and socio-economic disciplines need to be integrated into a single system. The individual components are as follows.

3.1. Hydrological Model: IHACRES

The hydrological model employed in this study is a modification of the IHACRES model [3]. The original model is based on the unit hydrograph concept and assumes that, after adjustment of rainfall at time step k for loss l_k, which depends on antecedent moisture condition, the stream flow (x_k) is a linear response to effective rainfall. The IHACRES configuration consists of n linear storage connected in parallel and/or series paths for the transit of excess rainfall to the stream. For the purpose of this particular research program, only 2 storage components, namely quick and slow flow, are identified. And the associated quick and slow streamflow outputs can be parameterized as follows:

$$x_k^{(q)} = -\alpha_q X_{k-1}^{(q)} + \beta_q U_k \tag{1}$$

$$x_k^{(s)} = -\alpha_s x_{k-1}^{(s)} + \beta_s U_k \tag{2}$$

$$x_k = x_k^{(q)} + x_k^{(s)} \tag{3}$$

The parameters $\alpha_q(\alpha_s)$ describe the rate of decay of a hydrograph following a unit input of rainfall. Parameters $\beta_q(\beta_s)$ define the peak of the quick (slow) component of a unit hydrograph. U_k represents effective rainfall and is defined as

$$U_k = S_k R_k \tag{4}$$

$$S_k = cr_k + \left[1 - \frac{1}{\tau_w(t_k)}\right] S_{k-1} \tag{5}$$

where r_k is rainfall amount and S_k is the catchment wetness index, which can be calculated from Equation (5).

The term $\tau_w(t_k)$ is potential evapotranspiration and is arbitrarily defined as a constant τ_w at 20 °C. This term can be calculated using Equation (6)

$$\tau_w(t_k) = \tau_w \exp[(20 - t_k)f] \tag{6}$$

where f is a temperature modulation factor [3, 4]. Parameter c in Equation (5) is called the volumetric constant. It is required that the model should be able to predict stream flow from ungauged catchment under a different land cover scenario. So this model is configured to transform volumetric constant c from a referenced gauged catchment to an ungauged one which has different size, average slope and land cover types [5].

3.2. Crop Model: Catchcrop

The crop model employed in this study is based on FAO's yield reduction function [6] which says;

$$Y_a = Y_m \left[1 - \left(k_y\left(1 - \frac{ET_a}{ET_m}\right)\right)\right] \tag{7}$$

where Y_a and Y_m is an actual yield and a maximum obtainable yield for each particular crop, respectively. Parameter k_y is a yield reduction factor owing to water stress. The term ET_a/ET_m is a proportion between summation of actual and potential evapotranspiration . For each ten days time step, the model has rainfall and irrigation amount as inputs and adjusts the level of soil water storage according to runoff, percolation rate, soil type and root zone depth. At the end of each time step, ET_a is computed as a function of a level of soil water storage. Water stress that occurs at each time step will be added up to estimate actual yield in the function shown above [7].

3.3. Economic Model

The main objective of the economic model is to simulate a decision on the optimal allocation of agricultural land into different crop choices under biophysical resources and socio-economic constraints of a representative farm by each RMU type. The Linear Programming (LP) technique is employed assuming that each household aims to maximize its gross margins. The main constraints consist of land holdings, irrigation water, labours, and capital. The model is solved on a seasonal basis allowing for a transfer of cash from one season to the next. The general form of the LP model can be illustrated as follows:

Maximize

$$z = \sum_{j=1}^{r} c_j X_j \tag{8}$$

Subject to

$$\sum_{j=1}^{r} a_{ij} x_j (=, \leq) b_i \qquad \mathrm{b_i} \geq 0 \quad \mathrm{i} = 1, 2, \ldots, \mathrm{m} \tag{9}$$

$$\text{all } \mathrm{x_j} \geq 0$$

where Z is the maximum gross margins from the activities chosen, assumed to be the objective function, c_j is the gross margin of a 1 unit of activity X_j which represents decision variable or activity j, (i.e., land allocated to crop, amount of livestock raised and other farm and non-farm income generation activities), a_{ij} represents amount of resource i required in activity x_j, b_i is resource availability (i.e., land, labour, water and capital).

The parameters of crop yield, price and water availability used in the LP model are all expected values based on the farmer's experiences of previous seasons.

3.4. Linkages

Figure 1 illustrates a system workflow for a single cropping season. For each node, at the beginning of the crop season, the decision making process of a representative farm of each RMU is simulated using the Linear Programming model. Output from each RMU is then aggregated up to the node level forming a picture of land use pattern chosen by the farmers for this particular season.

This land use pattern then becomes a part of inputs into crop and water allocation module. Within the water allocation module, irrigation requirement (actual crop water requirement ∗ conveyance efficiency ∗ management efficiency) is determined on a 10 days time step basis. For each time step, simulated stream flow data is queried to see whether irrigation requirements are met. If water availability is greater than requirement, an amount of water equal to the irrigation requirement is diverted into the irrigation system. In the case of water deficit, available water is distributed evenly for each unit area of irrigated farmland regardless of actual demand. Different water allocation rules can also be set.

By the end of each season, the crop model will provide the actual crop yield owing to climatic conditions and water

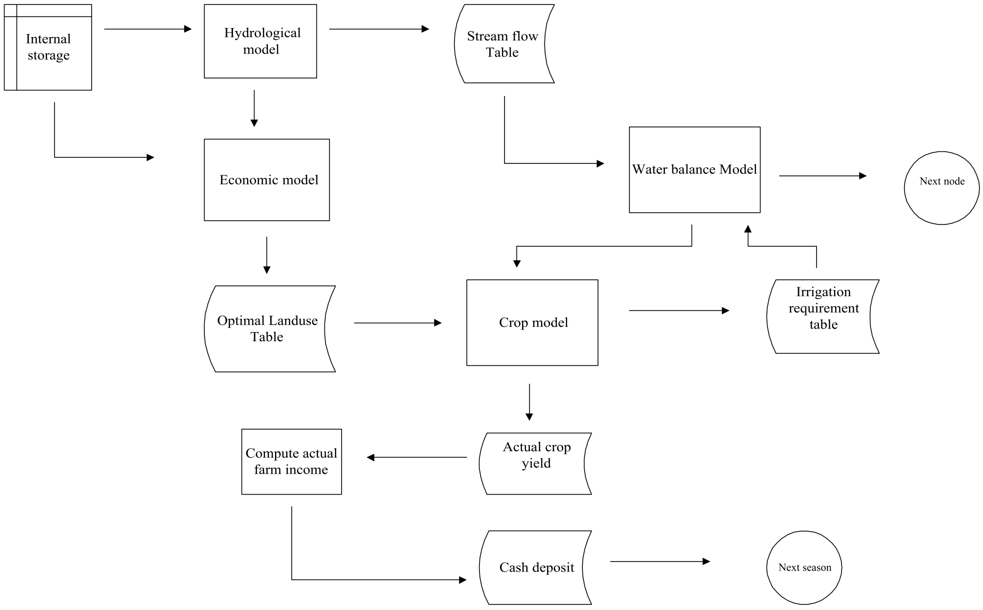

Fig. 1. A flow-chart of a model.

availability. In this study, rice sufficiency is set as a social constraint such that if the rice output is less than the consumptive need, actual farm income is reduced by the value of the rice deficit. The actual benefits and gross margins of crops and other activities selected by the LP model are then calculated.

The aforementioned process can be repeated over and over from one crop season to another in a given node. In a seasonal transition routine, outputs from biophysical simulation are fed back to adjust parameters in the LP models. Preferably, simulation should begin in the rainy season. In a wet-to-dry seasonal transition, a feedback mechanism sends back stream flow data to compute the amount of (expected) available water for the dry season. This feedback mechanism does not function during dry-to-wet transition because water availability in the wet season depends largely on the coming monsoon and prior knowledge is unattainable. Hence it is computed using a moving average of available rainfall records.

The cash deposit obtained by the end of each season is transferred to the next season and becomes the capital constraint in the LP model. Candidate activities are set according to prior knowledge about farmers' activities in wet and dry seasons. Gross margin (c_j) for each cropping activity is determined by simulated fluctuation in market price and expected yield obtained from crop model in the same season of previous years.

3.5. Possible Scenario Setting

Making use of a simulation system, which has been designed to take account of existing conditions, will give resource planners/managers a better understanding of current resource use situations and the driving force(s) behind them. The system also provides the capacity for users to set up scenarios, which would enable them to explore the possible outcomes. Examples of scenarios include climatic and policy scenario. The system is capable of handling a limited set of policy scenarios. The major one we are focusing on is enforcing forest conservation regulation. This scenario is based on the fact that farmland is overlapping with conserved forest. Enforcing the regulation will reduce the average farm size in the upland area, and set a new land holding constraint in the LP model. Reduction of farm input cost or increasing gross margin of a certain cash crop through a government subsidy mechanism is another possible scenario in the policy category. A subsidy scenario can be set in combination with introducing a new cash crop into the target area to see whether the farmers will switch to the new crop.

4. OUTPUTS AND IMPLICATIONS

As illustrated, the model provides the output on land and water allocation that can maximize gross margin to the communities within the node (sub-catchment) by taking into account the biophysical and socio-economic constraints specific to the area. The effects of a partial change in land uses, prices, investment and other development plans on farm gross margin, labour and capital requirements can be easily assessed and the results can be presented both at the non-aggregated RMU (household) level and the aggregated (node or catchment) level.

The economic and environmental trade-off of various plans can be explored for improving people well-being. Water is a very important shared resource. The integrated model can help to determine management strategies which will avoid or resolve conflicts arising from disputes over the uses of water.

However, users should keep in mind that although the output is quantitative in its nature, this integrated model aims to provide resource use options rather than quantify the amount of resources used.

5. MODEL ANALYSIS

5.1. A Study Catchment

This section discusses the results of testing the integrated model in Mae Uam sub-catchment located in the middle part of Mae Chaem catchment. Mae Uam's centroid is at latitude 18° 33′ 0″ North and longitude 98° 25′ 12″ East, covering approximately 43.75 km^2. Agricultural areas account for 10.6 per cent of the catchment, leaving 89.4 per cent for natural forest cover. Farming activities consist of two major types, lowland paddy fields and rain-fed upland. Figure 2 illustrates the major land cover types in this sub-catchment in 1997. For the purpose of this simulation, Mae Uam is split into 2 nodes as shown in Figure 2.

Only three major types of RMU exist in Mae Uam. RMU type 2 owns only irrigated paddy land, type 3 owns only upland rain-fed fields and type 8 owns both paddy and upland rain-fed fields.

5.2. Empirical Result

5.2.1. Pattern of Resource Use

Figure 3 compares the proportion of simulated land allocated to selected crops in the wet season of the year 1997 with the proportion of areas allocated to each crop gathered from the field survey in the same year.

From the field survey, paddy rice, upland rice and soybean accounted for 61%, 29% and 10% of agricultural land, respectively. The results from the simulation indicate a similar pattern, but the soybean area is so small that it is negligible. So, in Figure 3, only paddy rice and upland rice are shown. These staples occupy 65% and 35% of agricultural land, respectively.

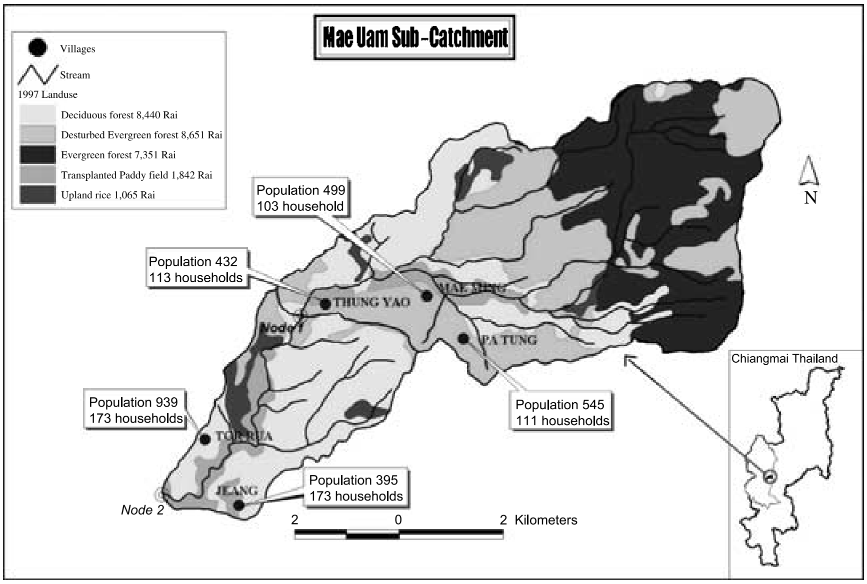

Fig. 2. Mae Uam sub-catchment.

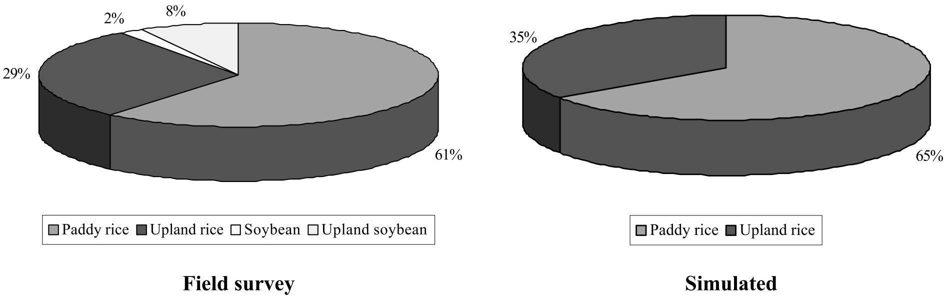

Fig. 3. Land use proportion, field survey vs. simulated.

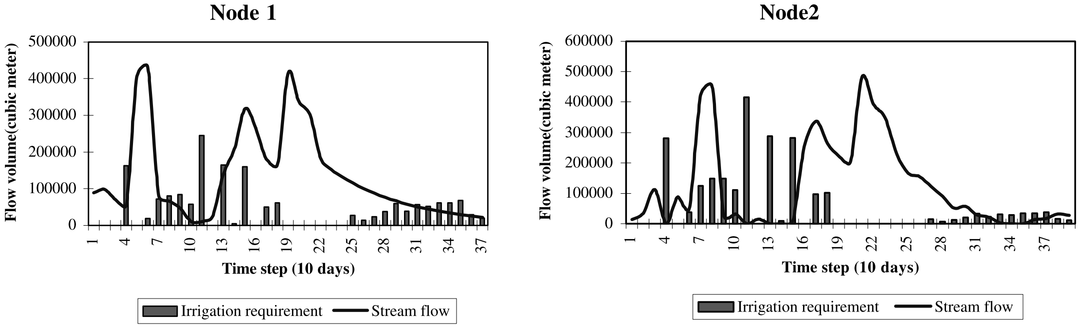

Fig. 4. Irrigation requirement versus stream flow.

During the dry season, only irrigated paddy land is able to be cultivated. Both field survey and simulation point out that soybean is the most suitable choice.

Figure 4 illustrates the total water demand versus stream flow in 10 day time steps during the crop year 1997/1998. Water deficit occurs in the middle of the wet season and at the end of the dry season in both nodes.

Table 1 compares the predicted crop yield from the crop model with the actual yield obtained during the field survey. In the case of upland rice, where yield depends solely on the amount of rainfall, the average yield differs from the actual value by only 4 per cent. The simulated paddy rice yield shows a greater variation from the actual value. Note that, although Figure 4 shows greater water deficit in node 2, the

Table 1. Comparison of crop yields in the simulation and field survey.[a]

Crop/Season	Simulation			Field survey
	Node 1	Node 2	Average	
Wet				
Paddy rice	473.0	541.0	511.5	509.4
Upland rice	206.0	260.1	233.5	243.1
Dry				
Soybean	210.1	210.1	210.1	215.4

[a]Unit: kilogram/rai.

Table 2. Gross margins per rai of selected crop, Mae Uam sub-catchment.[a]

Crop/Season	Value of farm output from simulation			Variable costs	Gross margin	
	Node 1	Node 2	Average		Simulation	Field survey
Wet						
Paddy rice	3121.8	3570.6	3375.9	1246.6	2129.3	2529.6
Upland rice	1442.0	1820.7	1634.5	817.1	817.4	1192.9
Dry						
Soybean	1617.8	1617.8	1617.8	792.9	824.9	1079.5

[a]Unit: baht/rai.

Table 3. Annual income per household.[a]

Season/RMU	Crop	Livestock	Agricultural employment	Total income
Node 1				
Wet				
Rmu2	7188.0	3082.7	6675.7	16946.4
Rmu3	3505.7	3082.7	6324.3	12912.7
Rmu8	10890.1	3082.7	7290.5	21263.3
Dry				
Rmu2	1429.4	3082.7	22222.9	26735.0
Rmu3	0	1541.4	17287.0	18828.4
Rmu8	1455.9	3082.7	24271.9	28810.5
Node 2				
Wet				
Rmu2	15514.9	3082.7	6734.4	25332.0
Rmu3	3400.9	3082.7	5571.4	12055.0
Rmu8	18809.3	3082.7	4528.0	26420.0
Dry				
Rmu2	1146.7	3082.7	22837.8	27067.2
Rmu3	0	3082.7	18571.4	21654.1
Rmu8	1167.9	3082.7	19014.3	23264.9

[a]Unit: baht/household.

simulated paddy area in node 2 is greater than that in node 1 by almost 2 times. So paddy rice in node 2 suffers less degree of water stress per unit area. Therefore, the simulated paddy rice yield in node 2 is greater than that of node 1. The predicted dry season soybean yield is equal in both nodes owing to the same reason. The predicted yield varies from the actual one by only 1 per cent. The highly precise outputs are owing to the fact that local maximum obtainable yield is used in the place of Y_m supplied by the model's author

The gross margins of wet season paddy rice, upland rice and dry season soybean are similar in both the field survey and the simulation. This result indicates consistency between the economic and biophysical simulation.

Table 3 shows the distribution of annual income per household for each RMU calculated from the simulation at the node level. The table's contents include both cash income and farm outputs consumed by household members. Annual income per household between node 1 and node 2 do not differ much. However, a representative farm of RMU type 3 who owns only upland rain-fed field earns the lowest income compared with the other RMU types.

As far as income distribution is concerned, the agricultural employment appears to be the major source of income for all households in Mae Uam sub-catchment, accounting for approximately 62 per cent of the total farm income. Cash and non-cash incomes from crop production and livestock account for only 25% and 13% of the total farm income, respectively.

6. CONCLUSIONS

With a growing population and increasing demands for improved highland watershed management, there is an obvious need to implement sustainable highland resource use that best serves the interests of the highland communities and the nation. To satisfy this need, an integrated model has been developed to aid decision-makers and various stakeholders in identifying and assessing options for highland resource uses. The model applies an integrative approach, combining biophysical data, with the perceptions and socio-economic conditions of the farmers in the given area. The model attempts to simulate the farmer's behaviour in selecting farming systems given relevant constraints and then aggregating up to the node and catchment level. The contributions of this integrated model include information about trends of land and water uses, gross margins or self-sufficiency of farm households in the highlands and the identification of possible conflict of interests.

The application of this integrated model to the case study of Mae Uam sub-catchment shows satisfactory results and therefore will allow users to systematically explore farmers' resource management options. This type of information should enhance understanding by resource planners/managers of how to plan and implement development schemes. However, farmers in Mae Uam sub-catchment still follow conventional practices, with the goal of achieving self-sufficiency. Therefore, their resource management patterns are less complicated than other sub-catchments where the farmers' production systems have a higher degree of market orientation. Further development of the economic model is required in order to address more complicated resource management patterns effectively.

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