A systematic approach to assess highland resource management options in northern Thailand

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Abstract: Problems that have emerged from the ongoing highland development schemes in northern Thailand indicate the need for better understanding of resource management issues in the region. Particular attention has been paid to land and water management. An integrated modelling system has been developed to address this issue based on a multidisciplinary approach. The components of the system include a crop simulation model, a hydrological model and a set of linear programming models. The modelling system enables users to simulate farmers' decision making process concerning farmland and water resource management. Conditions for farmers' decisions are adjusted seasonally and annually, by an embedded feedback mechanism, according to the simulated biophysical (water availability and the associated crop yield) and socioeconomic environments. Users are then capable of exploring the dynamics of land and water use options at the catchment and sub-catchment level. Such capability will enable them to look at resource management problems from both biophysical and socioeconomic perspectives and then make more informed decisions in planning future development schemes. The paper also presents preliminary results from calibrating the system against an existing scenario in one of our focused sub-catchment.

Keywords: resource assessment, integrated modelling

1. INTRODUCTION

Drastic deforestation and resource degradation in Thailand has long been recognized, drawing much attention and activities from both government organizations and non-government organizations. The common objective of these activities is attempting to balance the major roles of the highlands: the environmental protection functions, especially maintaining watershed functions; and, the productive functions, including agricultural production and forest products for the traditional highlands 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 humans and natural resources.

In this project (Integrated Water Resource Assessment and Management Project), the decision support system (DSS) is developed by linking the biophysical constraints to socio-economic conditions. The outputs on economic environmental tradeoffs will assist the stakeholders to assess various management options. The DSS also allows users to build limited scenarios such as external price shock, legal or institutional set up 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 and policy makers.

2. DSS FRAMEWORK

Being an agent for the driving force behind the changes in highland resource uses, the farm or household is considered to be the center of this analysis. The decisions on agricultural land and water uses are made in response to resource endowments, economic conditions, and socio-cultural norms of the household or communities.

2.1 Resource Management Unit (RMU)

Farms or households are classified into different types, called resource management units or RMU [Scoccimarro et al., 1999]. In IWRAM Project analysis, we assume that the two main biophysical factors that influence the types of crop selected by each household are the type of land (i.e., upland or lowland) and access to irrigation water (i.e., rainfed or irrigated). Therefore we can typically divide 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 catchment level.

2.2 Modelling at the Node Level

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 hydrological viewpoint, a node represents a sub-catchment and a network of nodes forms a catchment. Hence each node 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 a socio-economic viewpoint, the characteristics of farm households, alternative land use options and 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 on how they should manage their available resources (land and water in particular) to their optimum level of production.

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

2.3 Modelling Engines

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

2.3.1 Hydrological Model: IHACRES

The hydrological model employed in this study is a modification of IHACRES model. 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. 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 were identified. They are called quick and slow flow components, and the associated quick and slow streamflow outputs can be parameterized as follows:

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

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

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

The parameters α_q and α_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

$$U_k = S_k R_k \quad (4)$$

$$S_k = cr_k + \left[1 - 1/t_w(t_k)\right] S_{k-1} \quad (5)$$

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

The term $\tau_w(t_k)$ is potential evapotranspiration and is arbitrarily defined as a constant τ_w at 20 ^{0}C. This term can be calculated using (6)

$$\tau_w(t_k) = \tau_w \exp\left[(20 - t_k)f\right] \quad (6)$$

where f is a temperature modulation factor [Jakeman and Hornberger,1993]. Parameter C in Equation (5) is called 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 [Schreider and Jakeman, 1999].

2.3.2 Crop model: Catchcrop

The crop model employed in this study is based on FAO's yield reduction function [Doorenbos and Kassam, 1979] which says:

$$Y_a = y_m^* \left[1 - \left(k_y^* \left(1 - \frac{ET_a}{ET_m} \right) \right) \right] \qquad (7)$$

where Y_a and Y_m is an actual yield and a maximum obtainable yield for each particular crop, respectively. K_y is a yield reduction factor owing to water stress. The term *ETa / ETm* 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 and percolation rate, soil type and root zone depth. At the end of each time step, *ETa* is computed as a function of a level of soil water storage. Water stress that occurs at each time step will be summed up to estimate actual yield in the function shown above [Perez et al., 2002].

2.3.3 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 at maximizing its gross margins. The main constraints consist of land holdings, irrigation water, labour, 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

$$z = \sum_{j=1}^{r} c_j x_j \qquad (8)$$

Subject to

$$\sum_{j=1}^{r} a_{ij} x_j (=,\leq) b_i \qquad (9)$$

$b_i \geq 0 \quad i = 1,2,\ldots,m$

all $x_j \geq 0$

where *z* is the maximum gross margins from the activities chosen, assuming to be the objective function, c_j is the gross margins 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 one unit of activity x_j, b_i is resource availability, (i.e., land, labour, water and capital).

2.4 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, a prior simulated stream flow data is queried to compare whether irrigation requirements are met. If water availability is greater, an amount of water equal to the irrigation requirement is diverted into the irrigation system. In 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 as a scenario.

By the end of each season, the crop model will provide the actual crop yield owing to climate condition and water 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 deducted by the value of rice deficit. The actual benefits and gross margins of crops and other activities selected by the LP model are then calculated.

2.5 Outputs & Implications

As illustrated, the simulation system 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.

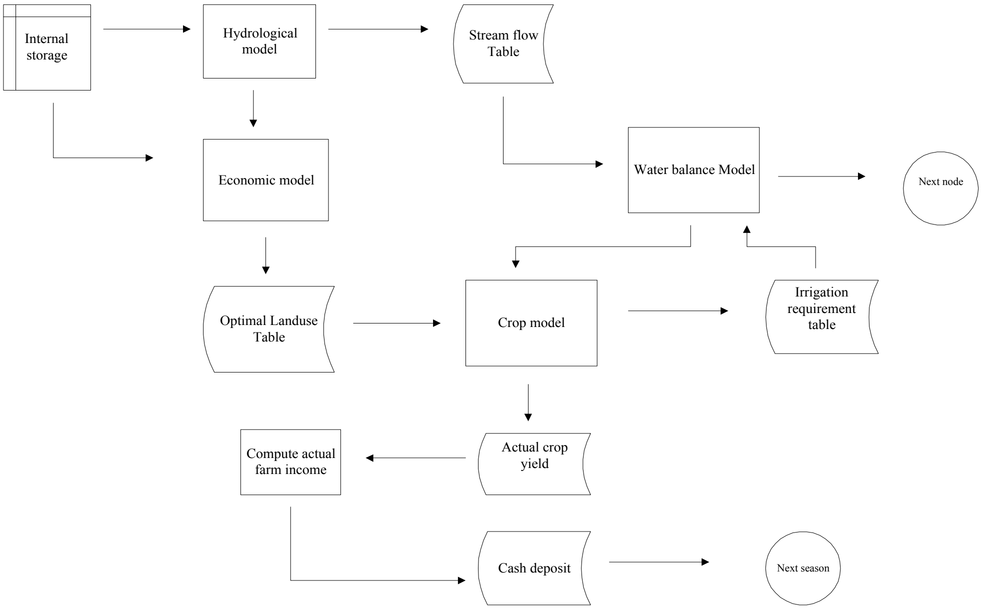

Figure 1. System workflow

The economic and environmental tradeoffs of various plans can be determined for improving welfare. Since water is basically a very important shared resource with lack of true ownership, the decision support system can aid assessing management options to help resolving or avoiding land and water use conflicts. However, users should keep in mind that although the output is quantitative in its nature, this DSS is aiming towards providing the trend of resource use options rather than quantifying the amount of resources being used.

2.6 Model analysis.

2.6.1 A study sub-catchment

The following session discusses empirical results from implementing our DSS in the Mae Uam sub-catchment located in the middle part of Mae Chaem catchment. The focused sub-catchment is divided into two nodes. Only 3 types of RMU exist in Mae Uam. RMU type 2 owns only paddy land, type 3 owns only upland rainfed field and type 8 owns both paddy and upland rainfed field.

2.6.2 Empirical results

From the field survey (crop year 1997/98), paddy rice, upland rice and soybean in the Mae Uam sub-catchment account for 61, 29 and 10 per cent 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, only paddy rice and upland rice are shown. Both staples occupy 65 and 35 per cent of agricultural land, respectively.

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.

Table 1. Crop yields, simulated Vs field survey
unit: kilogram / rai

Crop / Season	Simulation			Field survey
	Node1	Node2	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

Table 1 compares predicted crop yield from the crop model with actual yield obtained during the field survey. The highly precise outputs are owing to the fact that local parameters are used in place of the original ones.

Table 2 shows the distribution of 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 consume by household members. 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 rainfed field earns the lowest income compare to the other RMU types.

As far as income distribution is concerned, the agricultural employment appears to be the major source of income for farm households in Mae Uam sub-catchment which account 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 per cent of the total farm income, respectively.

2.7 Conclusions

With growing populations and 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, the DSS is developed to aid decision-makers and various stakeholders in identifying and assessing options for highland resource uses. The DSS applies an integrative approach, combining biophysical data, perceptions and socio-economic conditions of the farmers in the given area. The DSS attempts to simulate the farmer's behavior in selecting farming systems given relevant constraints and then aggregating up to the node and catchment level.

The application of the DSS to the case study of Mae Uam sub-catchment shows satisfactory results. Hence it allows our users to systematically explore farmers' resource management options. This type of information should enhance better understanding by resource planner/manager about how to plan and implement development scheme. However, farmers in Mae Uam sub-catchment still follow conventional practices and aim towards self sufficiency in their production. Therefore their resource management patterns are less complicated compare to the other sub-catchments where farmers' production system has a higher degree of market orientation. Further development of the economic model is required in order to address more complicated resource management patterns effectively.

Table 2. Income per household (baht per household)

Node1 Season / RMU	Crop	Livestock	Agricultural Employment	Total Income
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
Node2 Season / RMU	**Crop**	**Livestock**	**Agricultural Employment**	**Total Income**
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

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