

IWRAM: An integrated modelling toolbox for considering impacts of development and land use change in Northern Thailand

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Abstract: The IWRAM Decision Support System was developed to consider economic, environmental, and sociocultural trade-offs involved with resource competition and development in the Mae Chaem catchment in Northern Thailand. IWRAM contains two modelling toolboxes utilising a nodal network structure for catchment analysis: a Biophysical Toolbox, for considering the biophysical (erosion, streamflow, crop) implications of 'painted on' land use scenarios; and, an Integrated Modelling Toolbox, which links models of household decision making with the biophysical toolbox to allow for consideration of socioeconomic and environmental trade-offs of many development and policy scenarios. This paper describes the Integrated Modelling Toolbox within the IWRAM system. Links between household decision models, a socioeconomic impacts model and the biophysical toolbox are described and results for a number of forest encroachment scenarios are demonstrated using key indicators of social, economic and environmental performance. The potential for reapplication of the modelling framework to a large number of catchment situations is also discussed.

Keywords: Integrated Assessment, IWRAM, modelling, water resources

1. INTRODUCTION

Throughout the world, agricultural intensification and the associated competition for water resources produce environmental, economic and social impacts. In parts of the developing world these problems are often more striking because of the need to improve food security and reduce poverty, and the associated rapidity of the manifested problems. Ghassemi *et al.* (1995) provide information on the extent and distribution of the world's water and arable land resources and land degradation types.

In Northern Thailand, agricultural expansion has produced competition for water at various scales, resulting in erosion problems, downstream water quality deterioration, groundwater depletion, biodiversity loss, and shifts in the distribution of economic and social well-being and equity. The monsoonal nature of rainfall also intensifies demand for water in the dry season, exacerbating instream biodiversity and habitat. This is especially the case for seasonal shifts in flow regimes at larger scales, where dam regulation is considerably greater.

The Integrated Water Resource Assessment and Management (IWRAM) project has been developing a methodology to assess these issues. The focus has been on working at the subcatchment scale (~100 km²) in the Mae Chaem catchment (4,000 km²), principally with the Royal Project Foundation and Land Development Department in Thailand, to provide them with a land use planning toolbox. Figure 1 shows the position of the Mae Chaem catchment within Thailand.

With respect to issues, initial attention has been given to the spatiotemporal distribution of water supply, erosion, rice deficit and farm income throughout case study catchments. This is in relation to input drivers such as climate, commodity prices, technological improvements, government regulations and investments. Lessons from this prototyping project are fully expected to facilitate the incorporation of other impacted sectors, such as groundwater and water quality, in the near future through a project focused in other northern catchments with these issues.



Figure 1. Mae Chaem catchment

In order to enhance the utility, interactivity and transparency of the approach, the toolbox has been embedded within a decision support system (DSS). The DSS contains models for hydrology, crop growth, erosion, and socioeconomic decision making. This allows scenarios to be generated as inputs to the toolbox and a range of biophysical and socioeconomic indicators to be provided as outputs. The main stakeholder focus for the DSS to date has been the Land Development Department which aims to utilise the DSS to assist its land use planning activities. However other agencies and groups have now become involved due to the national interest in integrated management at catchment and basin scale. Adoption is being facilitated by training workshops on the individual model components and the DSS itself.

This paper details an Integrated Modelling Toolbox which has been developed as a part of the IWRAM DSS. This toolbox comprises biophysical modelling tools (erosion, crops, hydrology) and socioeconomic decision and impact models.

2. SCALES IN INTEGRATED CATCHMENT ASSESSMENT

An important consideration when constructing DSS is determining the appropriate scale at which modelling should take place. This scale is determined by the key features of the issues focussing development of the DSS, as well as by socio-cultural considerations in the management of the resource. Spatially, the IWRAM Integrated

Modelling Toolbox represents resource management decisions as taking place at the household scale. Representative household types are delineated and with knowledge of their number, decisions simulated by the household models are lumped up to nodes at stream points of residual catchments (see Section 4). The household scale was chosen as it was considered that the household was the main driver of agricultural production decisions in Northern Thailand (Scoccimarro *et al.*, 1999). Future applications of the nodal network integrative framework utilised by the IWRAM DSS may rely on a different scale of decision making (eg. the regional or village scale) and will almost undoubtedly include additional types of resource users, such as industry or aquaculture. The IWRAM framework which has been developed is sufficiently generic to allow for these alterations. Temporally, the range of scales vary according to the needs of the various models to capture the dynamics of processes that require representation. Thus hydrologic models run on a daily time step to respond to the effects of intense rainfall. The crop model runs on a 10-day time step to reflect changing soil moisture conditions. The socioeconomic models run on a seasonal (wet, dry) basis to reflect seasonal cropping and production decisions.

3. FRAMEWORK OF THE INTEGRATED MODELLING TOOLBOX

The Integrated Modelling Toolbox consists of a number of modelling components: socioeconomic decision making models; a biophysical modelling toolbox; and, a socioeconomic impact simulation model. The biophysical toolbox consists of a crop model, CATCHCROP (Perez *et al.*, 2002), a hydrological modelling component (Merritt *et al.*, 2001a), a water allocation model, and an erosion model (USLE). The way in which the socioeconomic models of the Integrated Modelling Toolbox interact with this Biophysical Toolbox is indicated in Figure 2.

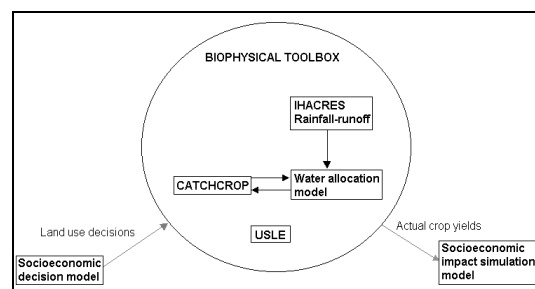


Figure 2. The IWRAM DSS (from Jakeman and Letcher, 2001)

Land use decisions, based on expected returns and water availability, are simulated within the socioeconomic decision models. These land use decisions are passed to the biophysical toolbox, which simulates the impact of climate on crop yields, water use, water availability and erosion. Actual yields and water use are then passed out of the Biophysical Toolbox to the socioeconomic impact simulation model, where the impact of actual yields on a series of socioeconomic indicators is calculated (see Section 11). A detailed description of the biophysical toolbox can be found in Merritt *et al.* (2001b).

4. NODAL STRUCTURE

In order to consider the impacts of household decision making on the hydrological system, and to model trade-offs between upstream and downstream users, the IWRAM DSS uses a nodal system to represent the stream network of a catchment. This means that household extraction decisions in a residual catchment area upstream of the node are aggregated and are modelled as occurring from a specific point along the river. Total water supply, modelled using a hydrological model (see Merritt *et al.*, 2001a), is also simulated at the node. Households in an area are divided into a number of representative Resource Management Units (RMU) and the decisions of individual households are aggregated by summing up the decisions of each RMU type present at the node (see Section 6).

5. HOUSEHOLD DECISION MODELS

Decisions on land and water use are modelled within the Integrated Modelling Toolbox as taking place at the household level. These decisions are made in response to expectations on the level of land, water and labour available to a household.

Households are classified into a number of different types, called Resource Management Units (RMU). For a detailed discussion on Resource Management Units and their application in the IWRAM Project see Scoccimarro *et al.* (1999). These RMU types differ according to their access to land and water in the catchment. For example, one RMU type may be households who own only irrigated paddy land, while households in another RMU may own both irrigated paddy and rainfed upland fields. Table 1 lists the three types of RMU that are used in the simulations in Section 9.

Land is classified into a number of different land units based on soil type and slope. A complete description of this can be found in Merritt *et al.* (2001b).

Table 1. RMU types

RMU	Description
2	irrigated paddy only
3	rainfed upland only
8	irrigated paddy and rainfed upland

In the model, households aim to generate as much profit as possible given a choice of crops, and expectations on the amount of land, water and labour that will be available to them. However other objectives such as maximising yield or minimising risk and uncertainty could also potentially be modelled. Social constraints, such as the need to grow rice as a subsistence crop during the wet season, are included as constraints on household decision making. For example, households are mostly limited to growing rice in the wet season in order to meet their subsistence needs. Cash cropping is assumed to take place in the dry season. The model allows for different choices of fertiliser level on crops as well as for the choice of whether to irrigate a crop. A cropping activity considered by the model consists of crop type, level of fertilisation and whether a crop is irrigated or rainfed.

The model uses linear programming to solve the constrained optimisation, using separate components for wet season and dry season decisions. At present only seasonal cropping decisions are able to be accounted for in the model. Decisions to grow perennial produce, such as fruit trees, are not currently considered by the model.

Households of the same RMU type are treated as having the same access to land, water and labour at a node. This assumes that the same land use decision is made by each of these households of an RMU type. Individual household decisions at the node are aggregated across individual RMU and then across RMU types and the aggregate land use decision is fed to the biophysical toolbox as an aggregated land use and management decision for the node.

Decisions made at the household level are fed through the biophysical toolbox and the impacts of actual crop yields and actual water availability are then simulated on the household. Rice deficits, as well as overall household economic performance, are simulated and used to indicate social and economic trade-offs involved with different scenarios.

6. MULTI-YEAR SCENARIOS

It is possible to run the Integrated Modelling Toolbox over several years or for a single year. If

the model is run over multiple years then the expected volume of irrigation water available to an RMU for each successive year (used in the household decision model) is updated on the basis of events in previous years. In the first year the expected quantity of irrigation water is that which was initially assumed by the user. In all other years the expected value is the actual amount of irrigation water used by the household in the previous year (i.e. naive expectations are assumed).

Once an integrated scenario has been specified, the socioeconomic decision model is run. This model calculates the area of paddy and upland devoted to different cropping activities in each season. In order for this land use decision to be passed to the biophysical toolbox, land use decisions made by the RMU on paddy and upland areas must be disaggregated by land unit, and totals over all RMUs for each crop activity must be calculated. This disaggregation procedure assumes that land units are developed in proportion to their current actual development first, before development 'spills over' onto other land units.

7. SOCIOECONOMIC IMPACT SIMULATION MODEL

The socioeconomic impact simulation model runs after the biophysical toolbox to calculate the impact of actual yield and water availability on household income and on total rice deficits. The algorithm used by this model can be described as follows:

1. Calculate the area weighted average yield for each activity.
2. Calculate the total yield of different crops for each household in each RMU.
3. Calculate the rice deficit for each household in each RMU. This is considered to be a social indicator of the impact of a scenario option.
4. Calculate the labour deficit/surplus for the household.
5. Calculate the household cash for each year given off-farm income, agricultural income and all production costs.

8. SOCIOECONOMIC INDICATORS

Outputs of the Integrated Modelling Toolbox are in the form of indicators. Biophysical indicators are also output from integrated scenarios which are the same as for the Biophysical Toolbox (see Merritt *et al.*, 2001b). These can be summarised as:

1. Crop yield (tonnes/ha);

2. Crop water demand (mm). Total crop water demand required for the crop to evaporate at full potential;
3. Irrigation (mm). Total irrigation applied throughout the season. If crop water demand does not exceed the amount of water available within the stream then irrigation is the same as crop water demand;
4. Postextraction streamflow (ML). This indicator shows wet season, dry season and annual streamflow following abstractions for crop irrigations;
5. Erosion (tons); and,
6. Forest area (ha).

Additionally, a set of socioeconomic indicators are also provided. These indicators can be given at various scales, by RMU, by node or by larger catchment scales. Changes in the social and economic 'performance' of a household due to different climatic and upstream land use choice scenarios can be investigated and tradeoffs can be evaluated among the indicators. Where a multi-year scenario is run, a time series chart of the output is provided. Tables of values are also given for all scenario runs. The socioeconomic indicators provided are:

1. Cash per household (baht). This indicator describes the 'economic performance' of households of each RMU type.
2. Total household income from agriculture (baht). This indicator describes the agricultural income from households' land use choices.
3. Off-farm income (baht). This indicator shows the reliance of different households on off-farm income.
4. Hire cost (baht). This indicator shows the total wages paid by households to hired labour in each year. It shows the extent to which production relies on hired labour.
5. Rice deficit (kg/household). It is assumed that each person in a household requires 300 kilograms of rice to survive. This indicator shows how much of this rice requirement must be met by purchasing rice (most households have a strong preference to produce their own rice).
6. Cost of rice deficit (baht). This indicator shows the cost to the household of purchasing unmet rice requirements.

A reduced set of indicators is used for considering trade-offs in this paper. Biophysical indicators are post-extraction streamflow (by wet and dry season), forest area and total erosion. The rice deficit and household net income (from on and off-farm sources) are also provided as indicators of the social and economic impacts of scenarios.

9. SCENARIOS AND RESULTS

To illustrate the way in which the Integrated Modelling Toolbox can be used to consider tradeoffs between stakeholders and also between environmental, social and economic outcomes in the catchment, results of a base case and price shock scenario are reported here. These scenarios have been run on the Mae Uam subcatchment. This subcatchment is modelled as two nodes in series. It is assumed for these results that householders have the same access to land and water in each case. The price assumptions for these scenarios are summarised in Table 2.

Table 2. Price shock scenario price assumptions (baht per kg)

	Base Case	Scenario 1
Paddy rice	6.6	4
Upland rice	6.9	4
Soybean	8.2	2
Maize	2	2

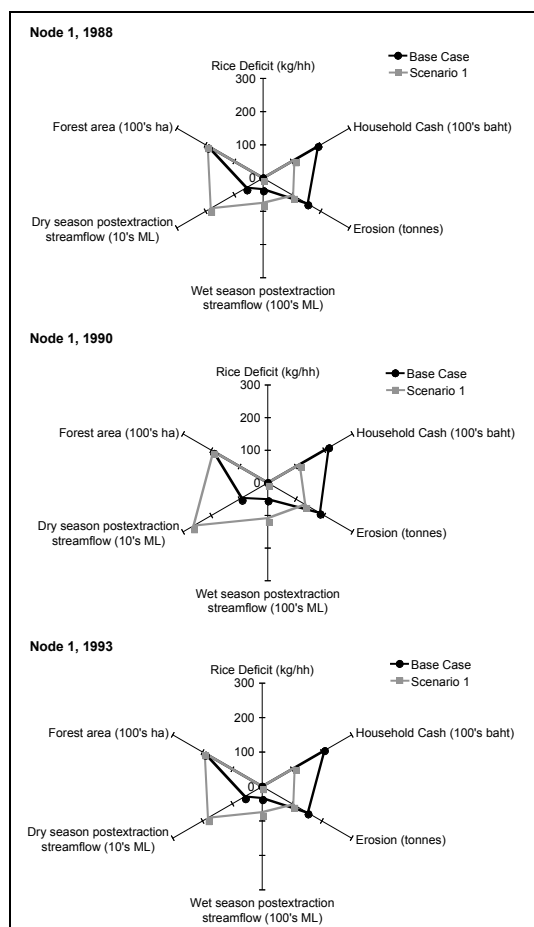


Figure 3. Results for Node 1

These scenarios were then run for three separate years, corresponding to different climatic regimes: 1988 (1391 mm); 1990 (1274 mm); and 1993 (1006 mm). The results for these runs for both nodes in Mae Uam are given in Figures 3 and 4.

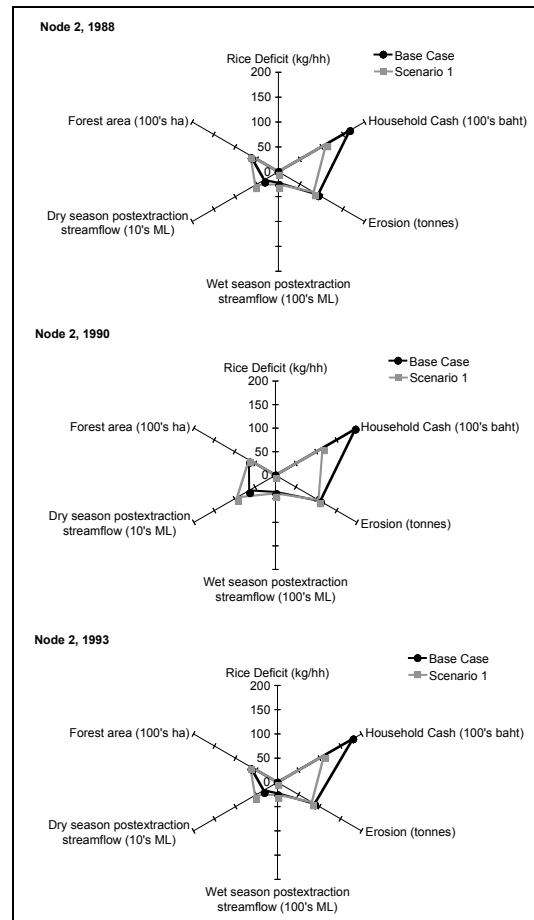


Figure 4. Results for Node 2

While the magnitude of the impacts shown differs between nodes and years, the pattern of impact is the same. The price shock (ie. price decrease) is associated with reduced impacts on the environment, with more streamflow left after extraction and smaller amounts of erosion at both nodes for all climate options (in the wet season for Node 2 this increase is very small). This is countered by a decline in household cash by roughly half. No rice deficit is induced by the change. Forest area stays constant since household access to land is assumed constant. These results show that a purely economic scenario, such as a sudden change in prices, can affect not only the economic and social performance of households but also the environmental performance of a catchment. In this case the change induced positive environmental effects. It is, however, possible to create similar scenarios which will have adverse impacts on the environment. In particular, for this scenario households were

restricted to using at most the same amount of land they are current using. It is possible that the pressure of reduced household incomes could induce increased deforestation as households attempt to maintain income with lower prices.

10. DISCUSSION AND CONCLUSIONS

This paper has outlined the development of an Integrated Modelling Toolbox to support decisions by illustrating the subcatchment and catchment-wide effects of land and water development options. It has been initially developed to consider subcatchments of the Mae Chaem catchment in Northern Thailand. The toolbox provides indicators of social, economic and environmental performance that change in response to a number of drivers, including climate and development of agricultural lands. The models in the toolbox have been developed to run on a scenario basis.

Results from a price shock scenario are shown in this paper. Other scenarios not shown in this paper which have been run include forest encroachment scenarios and migration scenarios. The results show the broad applicability of the modelling approach used within the Integrated Modelling Toolbox. Due to the complex, nonlinear nature of the models and their interaction, further work needs to be done to test the sensitivity of the model to changes in assumptions, so as to provide estimates of the uncertainty in these results.

Future work on this framework will be done to ensure it is applicable in other catchments within Thailand, and also in other countries. Components for considering urban and industrial water use, as well as for other resource intensive primary products such as aquaculture, can be considered in future developments of the system.

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