How Bad Isn't the Agent-Based Model CATCHSCAPE?

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Abstract: Due to mounting human pressure, stakeholders in northern Thailand are facing crucial natural resource management issues. The impact of upstream irrigation management on the downstream agricultural viability is a common source of conflict. It has often both biophysical and social origins. CATCHSCAPE has been developed as an Agent-Based model that enables us to describe the whole catchment: hydrology, farmers' behaviour and water management rules. It is meant to simulate scenarios based on assumptions about value of these features as well as some assumptions about context, such as levels of prices for various commodities or climate. The biophysical modules are made of a hydrological system with its distributed water balance, irrigated schemes management, crop and vegetation dynamics. The social dynamics are described as a set of resource management processes (water, land, cash, labour force). Water management is described according to the actual different levels of control (individual, scheme and catchment). Virtual experiments according to a first defined plan are made with two aims: sensitivity analysis of the model through variation of different parameters and extreme scenarios on one hand; overall behaviour of the basin under various realistic scenarios on the other hand. Both sets are meant to give more insight on the consequences of this very virtual catchment behaviour and improve the collective understanding on the real basin. Simulations show that the model is quite robust from a variation of results point of view and help to identify key factors such as farmers' representation on the expected amount of water for a cropping season or pluri-annual climatic trends.

Keywords: Multi-Agent System; Water Management; Catchment; Northern Thailand; Integrated Modelling.

1. INTRODUCTION

Three decades of agricultural transformation in northern Thailand has witnessed increasing tension in relation to natural resource management. On one hand, upland settlers are accused of reducing streamflow, through deforestation, and, on the other hand, downstream farmers are increasing their demand over water. As a matter of fact, forest is a dominant feature in many Northern Thailand catchments. Besides its religious and gathering role, it is assumed that forest cover strongly contributes to the local hydrological pattern. Meanwhile, most catchments are characterized by the expansion of irrigated schemes and the development of horticulture in the lowlands. Given that economically successful upland minority groups are often identified as the primary agents of environmental destruction, it can be a challenge to separate bio-physical reality from ethnic prejudice and socio-economic envy. Recent literature on environmental issues suggests that communication between stakeholders may provide a basis for consensual outcomes, especially if the process is based on underlying stakeholder interests rather than explicit stakeholder positions. But stakeholders need descriptive, integrative and anticipating models in order to share a common view and to reach a sound consensus [Doran, 2001]. CATCHSCAPE has been designed to achieve such a goal in Northern Thailand [Becu et al., 2001]. First, we outline CATCHSCAPE modelling sequences, agents and methods. Then, we describe the different methods used to test the robustness and sensitivity of the model. Finally, simulation results are provided and discussed.

2. MODEL DESCRIPTION

2.1. An agent-Based Representation

A complete description of the study case and of the model are given in Scoccimarro et al. [1999] and Becu et al. [2001]. Thus, we are just outlining in this paper the features of CATCHSCAPE concerned with the different tests applied and the results provided.

The catchment has been schematically represented in order to sketch the different levels of organization of the relevant spatial units. First, the Land Units combine soil texture, soil depth and land slope information. The second spatial representation concerns Land Use: Paddy, Upland and Forest. The Paddy zone is an irrigated area composed of a multitude of bounded terraces on which farmers mainly crop rice during the wet season. The Upland zone is constituted with rainfed plots spread all over the hillsides and cropped either with rice, soybean or vegetables. Forest is described as a sempervirens sole type cover. The unit cell (Plot) that composes the modelling grid (44*45), corresponds to a 2-rai farm plot (1 rai = 0.16 ha), which is the average size encountered in Northern Thailand catchments.

In order to focus on social interactions and resource management, we have first defined the farmers as cognitive agents (Farmer) and then, the other elements that compose the farmer's environment: the Crop, the River, the irrigation Canal and the Village have been created as reactive entities. Farmers are characterized by their family size and labour force. They can initially own upland and/or paddy plots according to their status. A paddy Plot belongs to a Canal. There are six Canals in the system, organized by pair and grouped into two irrigated schemes: one upstream with two Canals and one downstream, with four Canals. A cognitive agent, called Manager, manages the weir controlling a Canal. The irrigated schemes belong to one zone each (Village) corresponding to the upstream and downstream groups of actual villages.

2.2. Biophysical Dynamics

The water balance model, called CATCHCROP [Perez, et al., 2002], is a double reservoir model that has been adapted to a distributed object-oriented structure. The Plot manages the inputs (rainfall and irrigation), outputs (runoff and deep drainage) and water storage in the soil reservoir. The Crop manages the root zone reservoir and calculates the actual evapo-transpiration (AET) at each time step (10-days period). The sum of AET during the whole cropping period is used to calculate crop yields.

The hydraulic system is composed of a River and a set of Canals. The Manager controls and modifies the weir diversion rates. At the beginning of a step, an initial flow enters the River above the upper weir and it is diverted into the different Canals and Plots. In case of water shortage along a canal, its Manager establishes a rationing plan for the remaining Plots to be irrigated.

2.3. Decision-Making Processes

First, Farmers plant rice at the beginning of the rainy season as long as their yield expectation doesn't reach their family needs. Then, Farmers choose the most profitable cash crop according to their financial constraints, labour force and water availability (Figure 1).

Except for rice during the wet season, the Crop choice is based on a simplified Linear Programming model, called CATCHECO [Walker and Scoccimarro, 1999], taking into account seasonal farming costs, water and labour requirements. Water availability corresponds to an expected water supply during the irrigation period. The Farmer's expectation is continuously updated according to the previous year achievements.

At the beginning of the dry season, Farmers have to decide whether they allocate part of their labour force to off-farm activities or not, by comparing the expected off-farm income with the memorized earnings drawn from dry season cropping. Then, he chooses the most profitable combination.

Finally, Farmers have to make decisions about land dynamics. Three opportunities are offered to the cognitive agents. First, Farmers can buy available Plots. The number of Plots and market prices are fixed and eventually updated at the Village level. Then, Farmers can decide to install irrigation on rainfed Plots (located in the uplands), in order to farm them during the dry season. Investment costs and Village's regulation limit the feasibility of the transaction. Last, Farmers can convert forest Plots into upland Plots. Again, investment costs and local policy control the rate of conversation at the Village level.

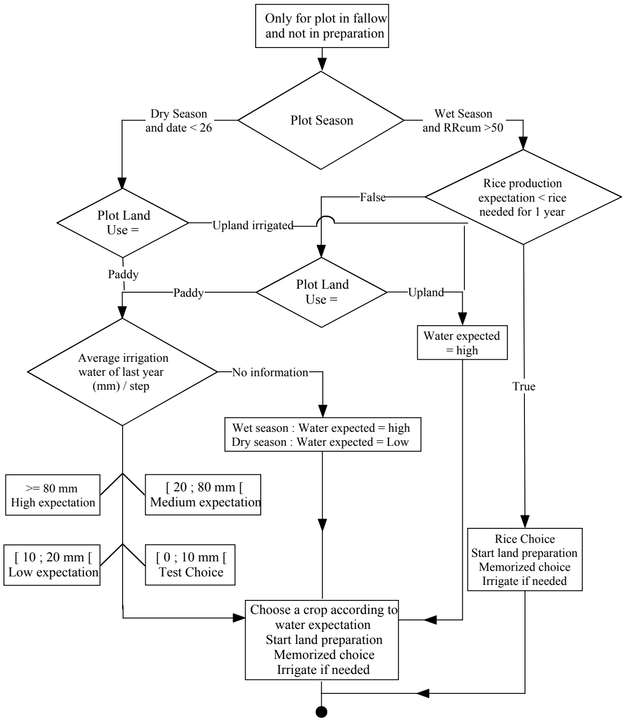

Figure 1. Crop choice flowchart.

2.4. Irrigation Management

Traditionally, farmers irrigate their fields with calibrated bamboo pipes (*piang*) provided by the canal manager. Equity comes from the respect of the watering duration and of the number of allocated pipes. Thus, Farmers have been entitled with a cheating probability function and ability to complain. The Canal constitutes the second level of management. Paired Canals enter into an irrigation rotation as soon as the downstream canal faces water shortage. The upstream Manager is forced to accept the rotation but may stop it if the River's streamflow comes back to normal. The irrigation scheme constitutes the third level of management. Negotiations involve Managers from different groups of paired Canals and, eventually, from different Villages. In this case, downstream Managers still send requests to the upstream ones but the latter are not forced to respond positively. The Manager's decision is based on the ratio between upstream and downstream water shortage. Criteria are more restrictive when negotiations are held between Villages.

2.5. Modelling Sequences

At each time step, CATCHSCAPE is divided into seven successive phases which are: (I) parameters updating, (II) cropping decision, (III) farming activities, (IV) biophysical dynamics, (V) crop harvesting, (VI) irrigation planning and (VII) land dynamic (Figure 2). Biophysical dynamics are activated before the next step irrigation planning. Thus, Farmers take decisions according to the previous existing situation and not the actual one. This delayed reactivity eventually generates, quite realistically, mistaken choices. More precisely, the Figure 2 shows also how the cognitive agents and the reactive entities interact over the different resources during each phase. The general dynamic of this highly non-linear system comes from the continuous overlapping and interweaving of the different component dynamics.

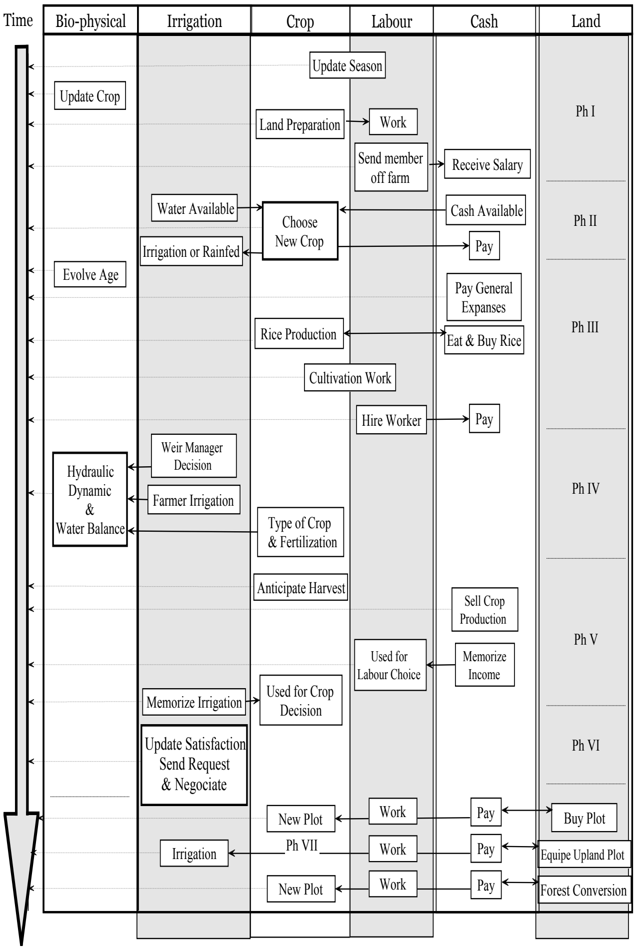

Figure 2. Resource Management flowchart. Each column corresponds to a given resource. Each box corresponds to a method activating this resource.

3. MODEL VALIDATION

3.1. Contingencies

We have established a formal Partial Validation Procedure (PVP) to test CATCHSCAPE. Each scenario was run over a 10-years period, corresponding to the existing climate data set (1988-1992). The scenarios were repeated 20 times in order to estimate the outputs variability. First, a BASIC scenario was created, corresponding to the experts' representation of the actual system. This scenario is described in Becu et al. [2001]. Then, several other scenarios were created to facilitate the PVP: (i) Stability testing (PeakPrice, Optimistic, Conflict), (ii) Sensitivity testing (Climate, Drought) and (iii) Virtual experiment (Thieves).

Several key indicators were chosen by the experts to assess the results of the different procedures. They encompass the biophysical, technical, social and economic features of the model: Crop Yield; Cash Position (Global, Rich, Poor categories); % of Dry Season Cropping; % of Paddy Cropped with Onion (wet season); Discharge in Canal x (x: 1 to 6); Satisfaction Level of weir Manager x (x: 1 to 6); % Off-farm Income (Global, Rich, Poor categories); % of Irrigated Upland Plots and % of Converted Plots.

For each scenario, key indicators were chosen and expected outcomes were written down *before the completion of the simulations.* Hence, results were discussed according to these initial assumptions (Ho). Any variation from the latter was analysed in terms model's coherence and agent's rationality. Whenever needed, the Mann-Whitney bilateral test was used to compare two different scenarios at a given date (statistical significance at $p = 0.05$). As results from S/O matching were presented and discussed in previous papers (Becu et al., 2001; Perez et al., 2002), this paper presents the three other procedures.

3.2. Stability Tests

First, yearly mean and standard-deviation values of the key indicators coming from the *Basic* scenario were systematically recorded. The objective was to test the influence of the random allocation of Plots to the Farmers during the initialization. Then, three extrem scenarios were built in order to test the stability of the model to different parameter settings.

PeakPrice simulates a sudden and temporary increase of onion price, from 6 bath/kg to 11bath/kg during Year 6 of the simulation. The predicted effect was a sharp increase of the Cash Position of the Rich category and a large extension of the % of Paddy Plots cropped with onions. *Conflict* prohibits the weir Managers from any kind of negotiation. Hence, the upstream Canals impose their views on the downstream ones. It was predicted that Discharge values and Landuse patterns would remain the same for Canal 1 (upstream) but that Discharge values and % Paddy Plots cropped during the dry season would decrease regularly from Canal 2 to 6.

Optimistic modifies the initial expectation of the Farmers concerning water availability during the dry season. The value of the corresponding parameter was turned from "low" (Basic scenario) to "high". It was expected that this modification would first drastically increase the number of Paddy Fields cropped during the dry season. Then, thanks to the learning method attributed to the Farmers, this number of Plots should converge with the *Basic* scenario one.

3.3. Sensitivity Analysis

In order to test the sensitivity of the model to the input data variations, we have started a series of simulations with different rainfall data sets. *Climate* constitutes a special scenario that randomly assigns one of the 5 contrasted climate files to each year of the simulation (repeated 20 times). It was predicted that the number of Paddy Plots cropped during the dry season would adjust quickly then remain stable over the period, avoiding the hieratic behaviour observed in the *Basic* scenario.

Drought replicates 10 times the driest climate file (corresponding to 1989). It was assumed that this artificial water shortage would decrease the Number of Paddy Plots cropped during the dry season, decrease the Cash Position of the Global population and increase the inequity between the downstream and upstream irrigated schemes.

3.4. Virtual Experiment

Thieves randomly allows 33% of the Farmers to steal water from the Canal. This scenario was called a virtual experiment as it corresponded to an actual issue discussed with stakeholders but we couldn't predict, at that stage, how the model would react. As far as stability and sensitivity tests were not completed and as long as social validation is not achieved through stakeholders' authentication, these results are purely speculative.

4. RESULTS

4.1. Stability tests

Mean and Standard Deviation values of several key indicators are provided in Table 1. According to these results and complementary ones, the Basic scenario appears reasonably stable. The most significant variability comes from the discharge values during the dry season. This result is not surprising as a variation of one or two irrigated plots has a great influence on the canal streamflow during this period.

Table 1. Mean values and standard deviation of several key indicators from the *Basic* scenario.

Year	[1]	[2]	[3]	[4]	[5]
Y1	5691	36.7	100.0	16.10	1.00
	94	*1.0*	*0.0*	*0.94*	*0.00*
Y3	4940	52.6	95.2	1.45	0.72
	192	*1.6*	*0.6*	*0.03*	*0.10*
Y6	13298	68.4	86.4	2.85	0.94
	712	*1.3*	*1.6*	*0.38*	*0.02*
Y10	9130	58.8	74.3	2.64	0.80
	557	*2.1*	*1.3*	*0.94*	*0.04*

[1] average cash position of the population (in baths), [2] proportion of paddy fields cropped during the dry season (in %), [3] proportion of soybean cropped during the dry season (in %), [4] discharge in canal 6 on 20/12 (in l/s), [5] Irrigation Satisfaction Criteria from weir Manager 3. First row: mean value, second row: standard deviation.

The drastic increase of onion price in the *PeakPrice* scenario influences the Cash Position of the Rich category as expected. But this positive effect concerns only the 6th year of simulation with a slightly negative impact the following. Meanwhile, the proportion of Paddy Plots cropped with onion remains the same with the *Basic* scenario. To understand this seemingly ephemeral effect we used an Individual Tracking method within the Rich category. It appeared that most of these Farmers used the their extra-cash to buy new Plots or equip their Upland Plots with irrigation instead of investing furthermore into onion cropping. This result partly confirms the ability of CATCHSCAPE to handle very sharp signals and perturbations.

The *Conflict* scenario doesn't modify the global indicators drawn from the *Basic* scenario. In fact, the lack of negotiation between Managers influences the distribution of wealth between the different Canals: dry season cropping increases by 15% along Canal 1 while it decreases by 5 to 10% in the other areas. Thus, we had underestimated the constraint supported by the upstream weir Manager (Canal 1) during the negotiation process. We also wrongly assumed a downstream cumulative effect. In fact, the dry season discharge in the Canals 5 and 6 is so low during the negotiations that few improvements are provided. Hence, CATCHSCAPE appears quite stable when the negotiation algorithms are turned off. But the sensitivity of the model is questioned and field validation should provide some insight concerning the situation during the dry season.

The *Optimistic* scenario was characteristic of a switch on/off test as the WAE parameter (Water Availability Expectation) takes only three values (high, medium, low). As part of the learning and decision making processes of the Farmers, the change of their initial expectation had significant consequences (Figure 3a). Compared with the *Basic* scenario, many Farmers quickly realized that their irrigated plots were not profitable. Thus, the number of Paddy Plots cropped during the dry season dropped sharply. Interestingly, from the 4th year on, this number of Plots remained significantly below the *Basic* one. Hence, CATCHSCAPE demonstrated a temporary high sensitivity to the value of this parameter. But the model showed also a resilient effect due to the irremediable losses of some Farmers during the global over-exploitation period.

4.2. Sensitivity Analysis

The *Climate* scenario confirmed the quick adjustment of the number of Paddy Plots cropped during the dry season. But, unexpectedly, this plateau was not sustained and the a significant drop was observed (Figure 3d). The only key indicator that provided some explanation was the % of Plots cropped with onions. As a matter of fact, this profitable and attractive crop is very water demanding . Thus, as a growing number of wealthy Farmers chose to crop onions, they condemned other badly located Plots to fallow. In terms of sensitivity, CATCHSCAPE demonstrates its ability to take into account purely socio-economic dynamics, disconnected from the high amplitude signals driven by the climate data.

An obvious consequence of the *Drought* simulations is the reduction of the number of Paddy Fields cropped during the dry season (Figure 3c). But, unexpectedly, this trend is not uniform unlike the Cash Position of the different categories of Farmers which is linearly decreasing. A comparison with the different key indicators showed that the discharge values of the different canals and the Irrigation Satisfaction Criteria (ISC) of the weir Managers were following the same non-uniform trend. Hence, the simulated Landuse pattern results from a complex and diachronic adequacy between water management (negotiations between Managers) and the water balance (streamflow/demand for irrigation). Further analysis showed that water shortage increased inequity along the different canals. Thus, CATCHSCAPE confirms its ability to provide a rational and relevant solution when confronted with a very limiting rainfall data set.

4.3. Virtual Experiment

The global influence of the *Thieves* scenario is very disruptive. The system is no longer sustainable, with 55% of the Farmers pertaining to the Poor category while some in the Rich category still enjoy prosperity. As the thieves are randomly distributed, their influence strikes all the Canals, resulting in a drop of the dry season cropping to nearly 23% (Figure 3b). This result is consistent with some discussions held in Northern Thailand, assuming that individual (mis)behaviour was much more disruptive for the irrigation schemes compared with control and negotiation from the weir Managers.

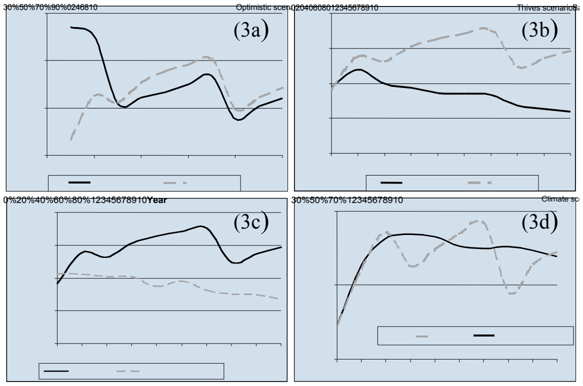

Figure 3: Evolution of the average % of Paddy Plots cropped during the dry season over a 10-years simulation. (a) Optimistic scenario, (b) Thieves scenario, (c) Drought scenario, (d) Climate scenario. 20 repetitions/scenario.

5. DISCUSSION AND CONCLUSION

Within the already existing MAS dedicated to water management, CATCHSCAPE brings original features. For example, the Farmers water expectation, through its influence on agents' decisions, plays a key role in the model. It reflects the great interaction between social and bio-physical dynamics.

At this stage, one has to consider the outstanding risk of playing God when creating these simulated worlds. Despite very delicate details and fine interlacing, they are only raw sketches compared with the actual reality. That is why we have tried to collect as much information as possible to try to validate CATCHSCAPE. In fact, the term validation is no longer adequate, as many interactions are beyond such an experimental approach. Authentication seems a better approach, as it requires forensic abilities and witnessing. Hence, the model will be used as a scientific representation of the reality and will be confronted with social representations through direct interviews and workshops with extensionists, weir managers and farmer's leaders. An alternative model will be eventually created, reflecting the different viewpoints. Indeed, we have fostered the clustering of different methods and tests to track any lack of coherence, stability, sensitivity and rationality within the model. This is an outstanding job to perform according to the number of combinations of variables and parameters. Thus, rather then arguably trying to prove how "good" the model is, we prefer to demonstrate how "bad" the model is not.

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