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CatchScape: an Integrated Multi-Agent Model for Simulating Water Management at the Catchment Scale.
A Northern Thailand Case Study.

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Abstract: Due to mounting human pressure, stakeholders in northern Thailand are facing crucial natural resources management issues. Among others, the impact of upstream irrigation management on the downstream agricultural viability is a usual source of conflict. It has often both biophysical and social origins. As different ethnic groups with tense relationships are involved, appropriate solutions should only emerge from negotiation. CATCHSCAPE has been developed through a Multi-Agent System approach that enables us to describe the whole catchment features as well with farmer's individual decisions. The biophysical modules simulate the hydrological system with its distributed water balance, irrigated schemes management, crop and vegetation dynamics. The social dynamics are described as a set of resources management processes (water, land, cash, labour force). Water management is described according to the actual different levels of control (individual, scheme and catchment. Moreover, the model's architecture is presented in a way that emphasizes the transparency of the rules and methods implemented. Finally, one simulated scenario is described with its main results as well, according to different viewpoints (economy, landscape, water management).

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

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1. INTRODUCTION

In April 1998, an extraordinary event took place in Northern Thailand. Five thousands lowland Thai farmers from the district of Chom Thong occupied and blocked one of the district's main roads. They were demanding the forced relocation of almost 20,000 hill-tribe villagers whom they accused to cause widespread environmental damage: deforestation, forest fires and streamflow drying. This event was the first sign of a emerging conflict between lowland and upland farmers of Northern Thailand about natural resources management [Walker and Scoccimarro, 1999].

As a matter of fact, forest is a dominant feature in Northern Thailand catchments (80% of the area). 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 an increasing water demand due to the expansion of irrigated schemes and the development of horticulture in the lowlands [Vanpen, 1986].
Thus, on one hand, upland settlers are accused of reducing streamflow, through deforestation, and, on the other hand, lowland farmers are increasing their demand over water. Moreover, the conflict is emphasized by ethnical differences between upland and lowland people. Regarding the complexity of the existing interactions, solutions may only arise from local negotiation. But stakeholders need descriptive, integrative and anticipating models in order to share a common view and to reach a sound consensus [Doran, 2001].

First, we outline the main characteristics for such an integrative model. Then, we describe CATCHSCAPE modelling sequences, agents and methods. Finally, some simulation results are provided and discussed.

2. INTEGRATIVE APPROACH AND MULTI-AGENT SYSTEMS

2.1. An Integrative Approach

Different modelling characteristics are needed to describe water management issues at the catchment scale. First, we need an integrative model as natural resource management largely interacts with other resources, i.e. local goods market, labour force basin or land tenure right [Cox, 1996]. Then, we need a large scale representation, including several irrigated schemes, to describe interactions between the different components of the systems of production, i.e. upland cultivation, off-farm activities, forest gathering [van Diepen et al., 1991]. Finally, we need to describe farmer's behaviour in order to simulate how "complex emerging rules often raise from simple individual behaviours and interactions" [Ferber, 1994].

There are just a few models dealing with both catchment and individual scale representations. SHADOC [Barreteau and Bousquet, 2000] simulates irrigation management in the Senegal valley based on individual behaviour. But the model is limited to a single scheme scale. Concerning groundwater management, SINUSE [Feuillette, *pers.com*.] represents several villages interacting for the resource.

Without explicitly taking into account the individual scale, the NELUP project [O'Callaghan, 1996] provides a good example of fully integrative Decision Support System (DSS). In northern Thailand, the DSS developed for the IWRAM project [Scoccimarro, et al., 1999] is built around the concept of Jointed Modules Architecture, where each module has a specific role but could be independent from the others. Modules are then activated successively. Such kind of architecture faces limits when different modules need to strongly interact.

In both cases, decision-making processes are based on maximization functions of farmers' incomes according to their available resources. This neoclassical approach tends to overestimate the self-regarding reactions and to override the propensity to cooperate of the economic actors [Gintis, 2000].

2.2. Multi-Agent Systems and Cormas

From a modelling perspective, non-continuous processes, multi-scale dynamics and simultaneous interactions characterize these complex adaptive systems [Holling, 1978]. Multi-Agent Systems (MAS) are closely related to the problem of complexity [Ferber, 1994]. When MAS are used to create natural resources management models, actual mechanisms are defined as a succession of simple rules that enter the flesh of the system dynamics. As several assumptions and simplifications must be taken, the model becomes only one representation of the actual system among many others. The advantage of MAS comes from their agent based, systemic and highly dynamic approach. As far as human behaviour is concerned, this kind of model is better described as prospective and exploratory rather then purely predictive [Bousquet, et al., 1999].

CATCHSCAPE was developed with the CORMAS platform under the VISUALWORKS environment [Bousquet et al., 1998]. Using object-oriented programming, CORMAS provides built-in facilities to the developer as a set of pre-existing entities and agents, control procedures and different types of interface to visualize the results. The spatial interface enables the user to specify and implement different viewpoints according to different specific issues.

3. MODEL DESCRIPTION

The Mae Uam catchment (43.6 km^2) includes five villages belonging to two different ethnic groups, Karen (upstream) and northern Thai (downstream),

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totalising approximately 2,600 people. Highly forested (83%), the catchment can be divided into two areas corresponding to the main irrigated schemes. The dominant issue is the assumed impact of upstream water management onto the viability of downstream farming systems. Information and data used to develop CATCHSCAPE are coming from field surveys, Thai Agency officers and ICAM database (CRES/ANU, Canberra).

3.1. Spatial Representation

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, according to the FAO methodology (DLD, Thailand). 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, mainly used for gathering and religious ceremony, 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 the Mae Uam catchment. In order to limit the number of cells the whole catchment has been reduced to its $2/5^{th}$.

3.2. Cognitive Agents and Reactive Entities

In order to focus on social interactions and resources management, we have first defined the farmers as cognitive agents (Farmer) and then, the other elements that compose the farmer's environment: the crops (Crop), the river (River), the irrigation canal (Canal) and the village (Village) have been created as reactive entities.

According to the $2/5^{th}$ ratio, 327 Farmers have been created. They are characterized by their family size and labour force. Farmers 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.

3.3. Biophysical Dynamics

The biophysical dynamics are simulated through a distributed water balance model and a hydraulic model.

The water balance model, called CATCHCROP [Perez, et al., 2001], 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.

3.4. Decision-Making Processes

First, Farmers choose the most profitable crop according to their constraints in cash, labour force and water availability. Figure 1 describes the choice flowchart used for each Plot pertaining to the Farmer.

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.

This initial Crop choice may be modified if the growth duration doesn't reasonably fit within seasonal boundaries. The planting date is delayed as long as Farmer's cash and labour force can't match the land preparation and planting requirements. At each time step, the Farmer is able to memorize and sum-up resources allocation for all his Plots.

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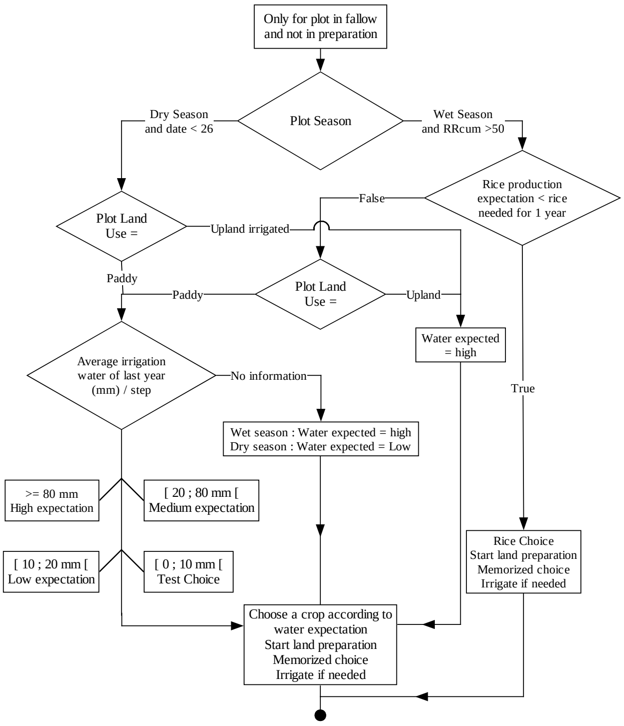


Figure 1. Crop choice flowchart.

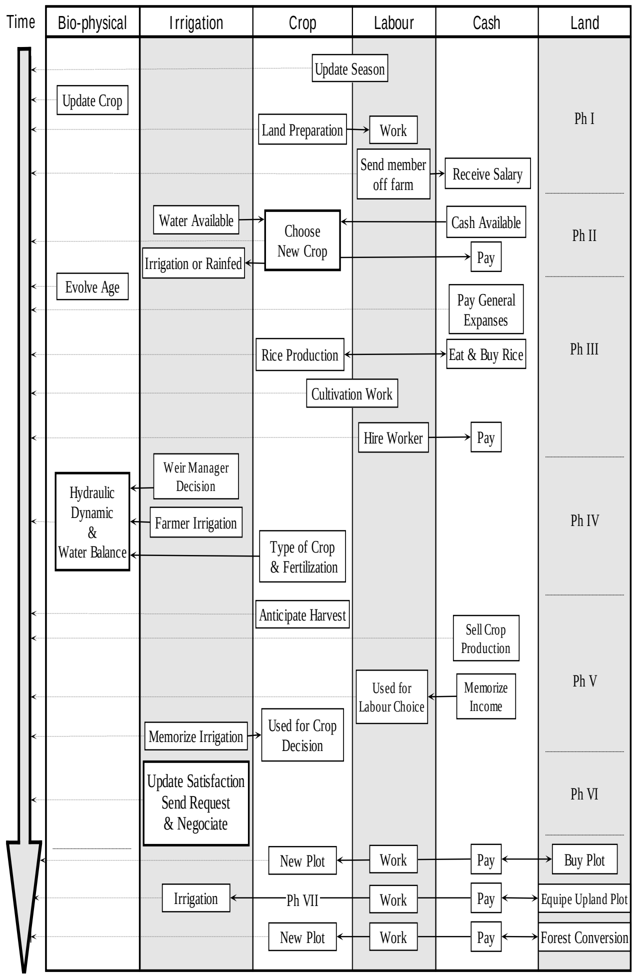
Even if paddy rice is a dominant crop in Mae Uam during the wet season, the LP analysis was unable to justify this planting strategy from a relevant economic viewpoint. Indeed, rice cultivation is mostly motivated by cultural and food security strategies rather than a purely economic decision-making process [Vanpen, 1986]. Thus, within the model, Farmers are forced to plant rice at the beginning of the rainy season as long as their yield expectation doesn't reach their family needs, cash and labour resources permitting.

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. As a matter of fact, only 30% of the paddy plots in Mae Uam are cropped during the dry season, mainly due to water shortage. Thus, part of the household's labour force is allocated to other activities. In the model, the Farmer compares the expected off-farm income with the memorized earnings drawn from dry season cropping. Then, he chooses the most profitable solution.

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. At last, Farmers can convert forest Plots into upland Plots. Again, investment costs and local policy control the rate of conversation at the Village level.

3.5. Irrigation Management

Concerning irrigation management in Northern Thailand, different levels of decision have been described [Vanpen, 1986]. The first one is the individual level. 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 later 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.

3.6. 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).

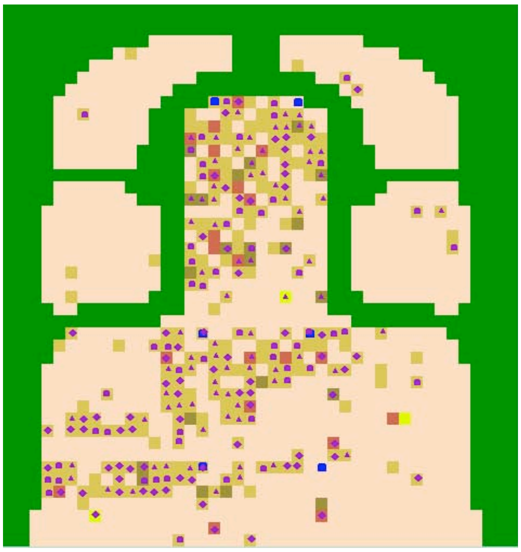
Biophysical dynamics are activated before the next step irrigation planning. Thus, Farmers take decisions according to the previous existing situation and not the actual one. This delayed reactivity eventually generates, quite realistically, mistaken choices. More precisely, The Figure 2 shows also how the cognitive agents and the reactive entities interact 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. Modelling sequences flowchart.

4. SIMULATION RESULTS

4.1. Different Viewpoints

Each scenario has been run over a 10-years period, corresponding to the existing climate data set (1988-1992). As several random functions are included in the algorithm, the scenarios have been repeated 20 times in order to estimate the outputs variability. CATCHSCAPE needs 40 minutes to achieve a 10-years simulation with a Pentium II processor. As shown in figure 3, the user can visualize the spatial and social dynamics during simulations according to different viewpoints (Cropping pattern, soil water balance, irrigation canal depletion, individual cash, conditions of negotiation…). At the end of the simulation, a set of indicators can be edited through evolution charts or export files.



Dark grey: forest; light grey: fallow; shaded grey: cropped plots. Dots, squares and triangles represent different types of Farmers. Scale: 1 grid cell = 2 rai (0.32 ha).

Figure 3. Visualization of the cropping pattern.

4.2. Basic Scenario

First, a Cluster Analysis has been applied to the ICAM database in order to define 6 homogeneous groups of households. The Farmers' attributes have inherited the following characteristics from these 6 clusters: number of plots (paddy and/or upland), family size, labour force and propensity to off-farm activities. Farmer's initial cash corresponds to a 6-month coverage of his domestic and farming expanses. In the basic scenario, the Village doesn't allow Farmers to convert the forest into farm plots, all agents are honest and negotiations between Managers are fair.

Table 1 gives average figures corresponding to the first and last years of simulation (20 repetitions). Obviously, social inequity has dramatically increased in the catchment at the end of the 10-year period. Approximately 10% of the Farmers enjoy a permanent positive cash position (Rich category) and gradually increase their wealth. Some of them are rich enough to invest into upland irrigation (15 cases). Meanwhile, 40% of the Farmers (Poor category) enter a permanent and worsening deficit position. The remaining 50% hardly maintain their economic buoyancy. Even if Farmers initially entitled with only 2 upland Plots partly feed the Poor category, the irrigated Plot location along the Canal largely contributes to its owner economic achievements.
For example, during the dry season, the upstream Canal (C1) can secure enough water to irrigated approximately 65% of its Plots. But the downstream Canal (C6) can hardly support 20% of the connected Plots. In this case, as Farmers were endowed with the ability to learn from previous failures, gradually, the number of attempts to crop during the dry season decreases.

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4.3. Alternative Scenarios

In order to test the sensitivity of the model and to figure out how the different components of the system were interacting, we have started a series of simulations with different parameters setting. At this stage, this work is far from being exhaustive. The scenario called CONFLICT describes a situation where there is no more negotiation between the Managers. Hence, the upstream Canals impose their views to the downstream ones. The scenario called THIEVES randomly allows 33% of the Farmers to steal water from the Canal. The scenario called EL NINO uses a specific climate file that duplicates 10 times the driest year (1989).

Table 1 shows that 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 C1 while it decreases by 5 to 10% in the other areas. The global influence of the THIEVES scenario is much more 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%. Amazingly, results from the EL NINO scenario are very close to the later. Except that the situation of the Poor category has worsen further and that – this time – even the Rich category is hit by the climate shift.

Table 1. Influence of the different scenarios upon several socio-economic indicators.

Scenario	[1]	[2]	[3]	[4]	[5]
Basic	5461 1691	6863 17990	60 134	36.6 41.2	0 15
Conflict	5663 1392	7191 17954	62 144	39.5 39.1	0 18
Thieves	5282 -4381	6648 13911	60 180	39.1 22.8	0 16
El Nino	3245 -6396	4530 10723	72 197	40.1 29.6	0 2

[1] average cash position of the population (in baths), [2] average cash position of the Rich category (in baths), [3] total number of Farmers in the Poor category, [4] proportion of paddy fields cropped during the dry season (in %), [5] number of upland plots converted to irrigation. First row: year 1, second row: year 10.

5. DISCUSSION AND CONCLUSION

CATCHSCAPE's architecture aimed at being integrative, spatially distributed and individual based in order to cope with complex and adaptive issues at the catchment scale. The actual version, through the modelling algorithms and the visualization wizards, provides relevant facilities to outline the evolutionary landscape patterns or to pinpoint specific agent's behavior.

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.

For example, we have crosschecked the simulated landuse pattern with the ones coming from remote sensing mapping. From 20 repetitions, the average proportions of the different Landuse types overlap with the actual ones with 80% accuracy. We have also compared the average simulated yields with the one coming from the local Thai Agencies. In the case of rice, soybean and onion, mean yields are simulated with, at least, 70% accuracy. From an economic viewpoint, the emergence of a small group of wealthy entrepreneurs corresponds to the actual situation in the catchment, confirming indirectly that ethnicity is not an issue in that case. The continuous impoverishment of the Poor category is less realistic but it has already helped us to rise new issues with our Thai colleagues about the access to credit.

Concerning the Farmers profiles, part of the initial material was coming from field surveys. But it is crucial to have the direct feedback from the stakeholders themselves regarding the social and individual rules implemented. This recognition by the concerned actors is the best known authentication.

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