Chapter VI

MAS modeling in Limbukha

The information generated from the diagnostic study and role playing games were used in conceptualizing the MAS model. The objective of the model was to represent the RPG and to facilitate integration of knowledge for better understanding of interactions among agents, to explain the effects of their decision processes and facilitate communication between two conflicting communities. Subsequent to the role-playing games in May and December 2003, a MAS model was developed which was called the "Limbukha model". Although the RPG is a resourceful tool, operationally they are cumbersome, slow in action orientation, and analysis of their results is difficult (D' Aquino et al., 2002a). For these reasons, peculiarly a MAS model finds its place in associations with a RPG as it facilitates handling of numerous parameters, produce speedy results, multiple options for experimentation, and importantly visualization of results.

In the case of Dompola RPG, the gaming process was limited to 5 to 7 time steps because of time and other practical constraints. The RPG helped in understanding and creating rules, which later were used in MAS simulations. A MAS model can supplement and complement a RPG, as they share a common representation of the complexity. MAS offer the possibility to represent individuals, their behavior and interactions, thereby representing emerging collective phenomena from micro level interactions (Ferber, 1999).

This chapter briefly describes the Limbukha model and the simulations generated from the model. Based on the findings from diagnostic studies, RPG and behavior of base model, 36 scenarios have been proposed here for further exploration.

6.1 Model structure: class diagram

The entities were identified and an initial class diagram was constructed to show all the model entities, attributes, methods, and their structural relationships

(Figure 32). While the attribute characterizes the entity, methods are the task entity undertakes in the model. The basic information on the linkages was derived from discussions with farmers and researchers. They are explained in the following sections.

6.1.1 Spatial entities

Spatial entities are made of elementary spatial entities and composite spatial entities. An elementary spatial entity represents the smallest homogenous unit of the environment in the model (a cell in CORMAS environment).

Plots

In Limbukha model, the plot represents the elementary spatial entity. It is considered as the smallest homogenous unit that corresponds to the lowest land unit (1 langdo = 0.1 ha) owned by any individual in Dompola and Limbukha. The basic interactions take place at plot level. The plot is characterized by 4 attributes: *plot number*, *myblock (*collection of plot belonging to one farmer*)*, *croppingpattern* and *crop*. The possible values of these attributes in the model are presented in Table 18. This entity undertakes only one operation (task) to update the status of the plot.

Table 18. Attributes of the elementary spatial entity in Limbukha Model

Attributes	Value	Represents
Crop	1 or 2	Rice and potato
plotNumber	1 to 8	Plot numbers in each field
myBlock	1 to 12	Field of 12 players
CroppingPattern	1-2, 0-2	0 = fallow; 1= potato; 2 = rice

Blocks

Each agent has a number of plots, which are collectively represented as block. In Limbukha model there are 12 fields assigned to 12 farmers depending on their category. As the plots are components of block, the block is considered as composite spatial entity in Limbukha model.

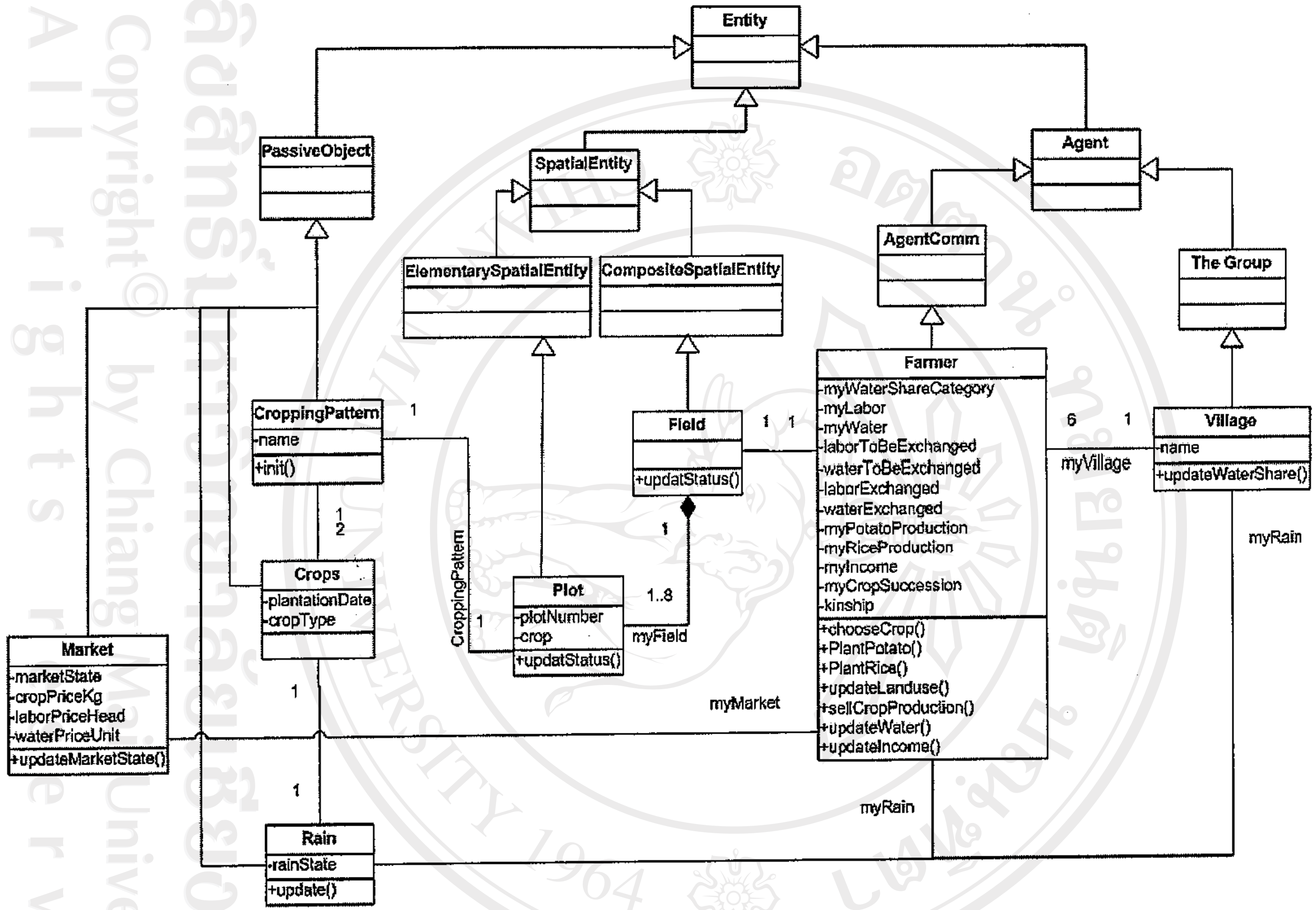


Figure 32. Class diagram of Limbukha model

6.1.2 Passive objects

Passive objects are collections of *exchanges* (message) of the *AgentComm* and simple objects. As the whole dynamics of the model is centered on farmer who is the communicating agent of the Limbukha model, they maintain constant interaction among farmers by way of sending the messages. In Limbukha model simple objects are *rain, croppingPattern, crops, and market.* Each simple agent has its own independent attributes and methods.

- *Rain*: the task of this object is to generate rainfall pattern for two cycles of the time step. There are two cycles in one time step, and each cycle can have either low or normal rainfall. It was done to relate the influences of rainfall on stream discharge and thereby irrigation water available.
- *CroppingPattern*: it is defined by either the potato-rice sequence OR the fallow-rice one depending on the rainfall pattern, market, and village conditions. It generates and initializes the crop succession for each time step.
- *Crops*: it is meant to define the crop type (potato or rice).
- *Market*: this object is meant to generate economic interactions. It is defined by 4 attributes (Table 19) and randomly generates market state as either low or high. It influences the economic calculation in the model and also the way players make their decisions regarding the crop succession for the next time step.

Table 19. Attributes of passive object "*Market*".

Attributes	State
marketState	It is an instance of object marketState.
cropPriceKg	It is an instance of object cropPricesKg
laborPriceHead	The wage of labor is used as US$ 2 per person day
waterPriceUnit	It is the price of water = US$ 2 per unit of water (1 day share).

- *Messages*: message is an object which helps agents to communicate and interact. In day-to-day life, it can be considered as mails (emails or any form of mails) or conversation among individuals. Any agent who needs to send message has to create an instance of a subclass of message and fulfill it. In Limbukha model there are 3 instances of message subclass and each subclass has a specific sequence of messages. For example Figure 33 shows instance: *exchangeWater* with 12 variables or types of messages. In Limbukha model messages have 3-4 attributes as explained below:

- *Sender:* it is the instance of the entity sending the message. But the entity sending the message can leave it blank (for anonymous message) or even fill it with another agent address. In Limbukha model farmer is the sender identified by their ID.
- *Receiver*: it is an instance of a class inheriting from AgentComm or GroupComm. It identifies an agent who receives the message. Every agent (farmer) has a mailbox and will be automatically registered by the channel, to receive mails from senders.
- *Symbol*: it is an attribute provided to signal the sense of communication. It can be any symbol to indicate that a conversation is taking place.
- *Amount*: it is an object describing an amount, like units of water, number of labor, and cash used in transactions.

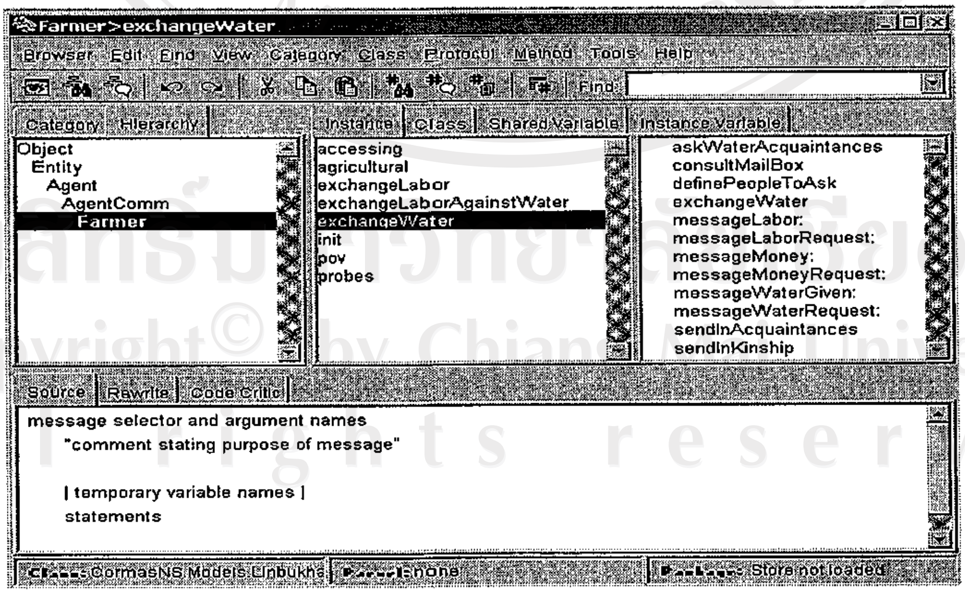


Figure 33. CORMAS window showing details of exchanges in Limbukha model.

6.1.3 Social agents

The social agents are defined by *AgentComm* and *AgentLocated.* It implies that the agents of this class can be spatially located, move to affect the environment and importantly be able to communicate with other agents. In Limbukha model, two classes of social agents are used as follows:

Farmer: in Limbukha model there are 12 farmers classified as AgentComm who communicate among agents and interact. Each agent is defined by attributes as given in Table 20. As communicating agent, farmer has to execute many tasks, it actually represents the dynamics of the model. Their tasks are presented in Section 6.2.

Table 20. Attributes of social agent (Farmer) in Limbukha model.

Attributes	Explanation
myWaterShareCategory	It is an attribute that differentiate among communicating agents
myField	Each agent has been assigned to field (1 to 12)
myLabor	Represents number of labor a agent has. Thruelpa has 60, cheep 80, chatro 180 and lhangchu has 160
myWater	It is the unit of water share each agent has depending on their category and rainfall pattern for each cycle
laborToBeExchanged	Excess labor that is available for exchange
waterToBeExchanged	Unused irrigation water that is available for exchange
laborExchanged	Number of work days received or given to *AgentComm*
waterExchanged	Number of water shares received or given to *AgentComm*
myPotatoProduction	It is the instance of potato production class
myRiceProduction	It is the instance of rice production class
myMarket	It is the instance of market class (high and low)
myIncome	It is the income gained in a year
myVillage	It is an instance of object village
myCropSuccession	It is an instance of object CropSuccession
kinship	It indicates who is related to whom, as kinship plays significant role in sharing irrigation water
peopleToAsk	List of acquaintances to ask for water
peopleToAskWater	List of all farmers to ask for water
twoCycleWaterExchanged	Sum of water exchanged in two cycles of a time step
firstCycleWaterExchanged	Units of water exchanged in first cycles of a time step
acquaintancesLabor	Labor from acquaintances

Village: there are two villages considered as *AgentLocated* in the Limbukha model. The villages are Limbukha and Dompola. The 12 communicating agents are assigned to either of the villages. Farmer 1 to 6 represent Limbukha and 7 to 12 represent Dompola, which is similar to the RPG. The village is defined by one attribute *name*: either Limbukha or Dompola. The only task it has is to update water share among villager after rainfall is initiated.

6.2 Model dynamics: behavior of agents

As explained earlier, farmers are the only communicating agent in this model. The way these agents behave and interact among themselves will influence the dynamics of the model. The behavior of agents can be classified into two broad categories as explained below.

6.2.1 Agricultural methods

In Limbukha model there are 8 tasks related to agricultural operations which an agent performs. Some of the major tasks of this model are explained below:

1. *decideCroppingPattern*: this is the first task that *AgentComm* has to do. As depicted in Figure 34, agent makes decision on the crop succession that will be used in that time step.

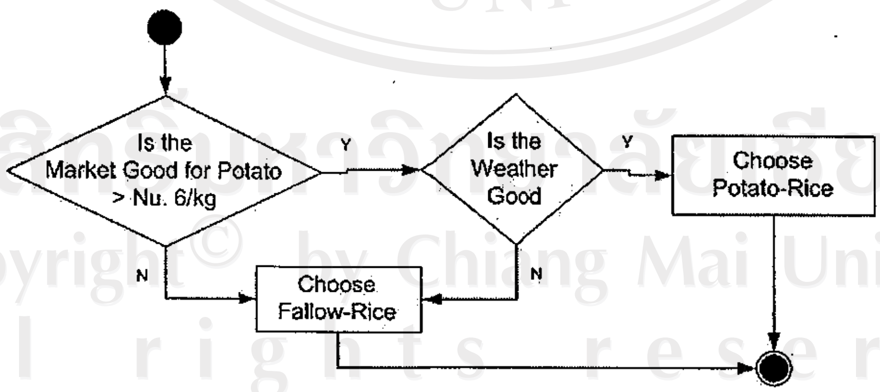


Figure 34. Process to decide a cropping pattern in the Limbukha model.

2. *calculateWaterLaborDemand*: depending on the fallow land, crop succession, water and labor allowance, agent calculates the requirement of labor and water. This task will help to find quantity of labor and water available for exchange (Figure 35).

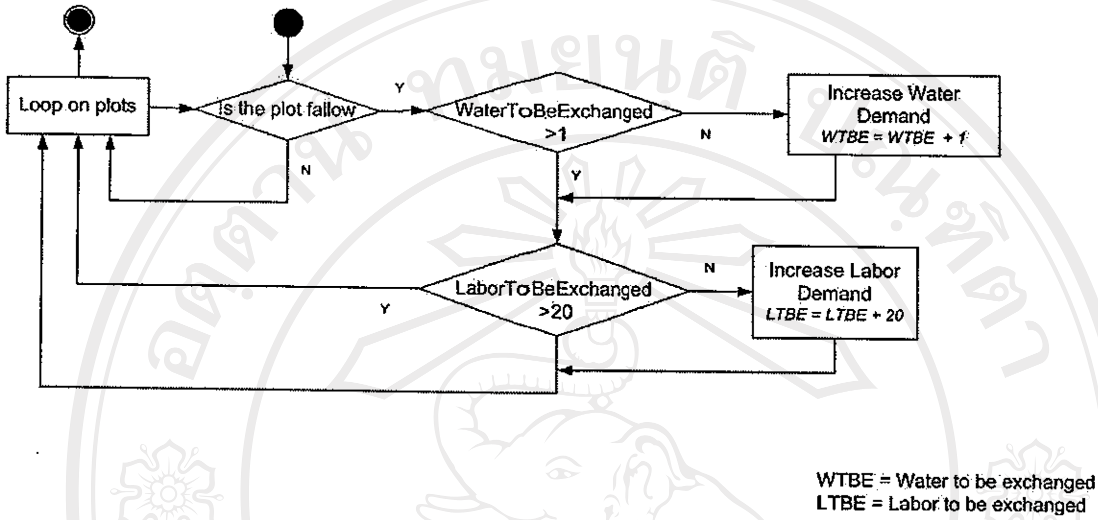


Figure 35. Process to calculate water and labor demand in Limbukha model.

3. *plantPotato*: agents of only Limbukha plant potato in the first cycle of time step (Figure 36).

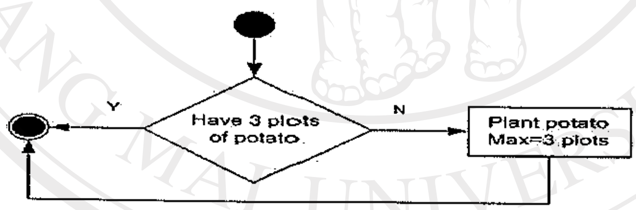


Figure 36. plantPotato task in Limbukha model.

4. *plantRice*: this task is used to plant rice in both villages in two cycles per time step (Figure 37).

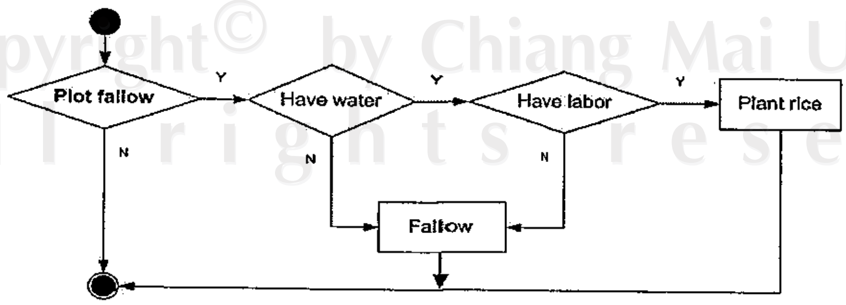


Figure 37. plantRice task in Limbukha model.

5. *exchangeWater*: in this task agent who need water send messages and interactions take place among agents. If the agent does not get water the plot is left fallow.
6. *harvestPotato*: this task is undertaken at the end of the first cycle by Limbukha farmers only to remove (harvest) potato from the plots, such that it is free for planting rice in next the cycle. In the same task, yield of potato and income of farmer is updated.
7. *harvestRice*: this task is executed at the end of the second cycle of each time step when rice planted during both cycles are removed. During the same task, rice yield is updated followed by update of income. With this task the time step (or crop year) ends.

6.2.2 Communication methods

The dynamics of Limbukha model also depend on the way agents communicate among themselves to accomplish different tasks as explained in the preceding section. Table 21 gives the detailed list of messages used in Limbukha model. Similar to Dompola RPG, three communication networks were used in the base model. Firstly, the network of kinship within a village: where an agent identifies itself as kin to another agent and gives water free of cost whenever available. Secondly, agents communicate with acquaintances of their respective village. In the last method, they were allowed to communicate with agents of the other village. A basic structure of communication method used in Limbukha model is described in the following paragraph.

Define people to ask: the first step before any request for water or labor is requested, other agents of the network are defined either as kinship or acquaintance. From the acquaintance group, each agent defines the other members as those with whom they can interact for exchange of water and labor.

Table 21. Instances of message subclass and their corresponding message used in Limbukha model

Instances of messages	Messages
exchangeWater	*askWaterAcquaintances; consultMailBox; definePeopleToAskWater; exchangeWater; messageLabor; messageLaborRequest; messageMoney; messageMoneyRequest; messageWaterGiven; messageWaterRequest; sendInAcquaintances; and sendInKinship*
exchangeLabor	*askLaborAcquaintances; consultMailBox2; definePeopleToAskLabor; exchangeLabor; messageLabor2Request; and messageMoney2Request*
exchangeLaborAgainstWater	*askLaborAgainstAcquaintances; consultMailBox3; definePeopleToAskLabor; exchangeLabor; messageLabor3Request; and messageMoney3Request*

Methods to ask: in Limbukha model three messages have been programmed to ask water or labor. Messages like *askLaborAcquaintances*, *askWaterAcquaintances*, and *askLaborAgainstWaterAcquaintances* are associated to send in request for labor to acquaintances, water to acquaintances and asking labor against water respectively. All these messages are sent to the mailbox of all acquaintances asynchronously.

Methods to answer the request: in every time step, all agents check their mailbox for any message requesting water or labor. If the receiver has excess of labor or water, the agent sends a reply to the sender. In case there is no unused irrigation water or labor the receiver will not reply to the message.

Methods to give: similar to replying to a message, the receiver sends in the requested number of labor or unit of water to the sender of the message. There are instances where receiver make return request for labor against water or even cash. The sender will pay back according to the request. Both receiver and the sender will update the account of labor, water and income.

6.3 Organization of interactions

6.3.1 Protocols of interactions

Agents may exchange either within a kinship network or among an acquaintance network. In this study 6 different protocols of interactions have been identified. The protocol that resembles reality to a certain extent is presented in Figure 38. Other protocols will be explained later. Figure 38 shows how agents "A" interact with agent "B" to get water. The process can be explained stepwise as follows:

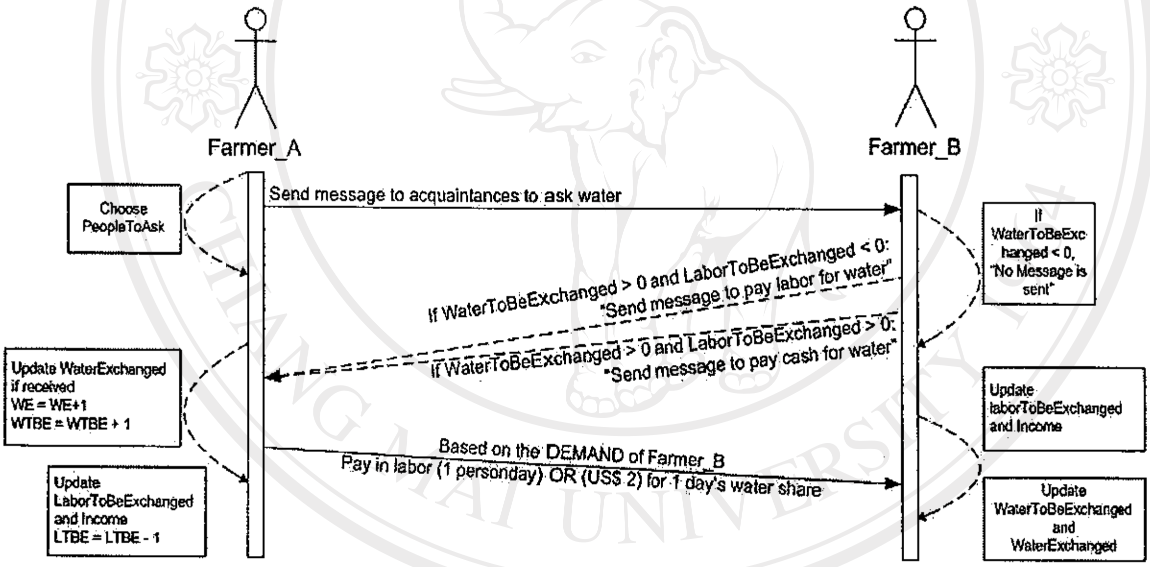


Figure 38. Protocol for exchange of water and labor in Limbukha model.

The successive steps involved in the protocol for exchanging of water and labor are as follows:

- Agent "A" identify acquaintances
- A send message to mailbox of B asking for water
- B opens the mailbox to see, if there is any request for water
- B will check his water credit or balance of water (*waterToBeExchanged*) and amount of labor available (*laborToBeExchanged*)
- If there is no credit, B will not reply to A

- Under the following conditions B will respond to A's mail:
    - If *waterToBeExchanged* > 0 and *laborToBeExchanged* < 0; B will send a mail to A asking to give labor against water.
    - If *waterToBeExchanged* > 0 and *laborToBeExchanged* > 0; B will send a mail to A asking cash for water.
- Based on the demand from B, A will make payment either in cash or labor.
- A will update *waterExchanged, waterToBeExchanged, laborToBeExchanged* and income.
- Similarly B will also update *waterExchanged, waterToBeExchanged, laborToBeExchanged* and income.

6.3.2 Overall sequence diagram for one time step

The sequence diagram shows how objects communicate with one another over time. The key idea here is to show the interactions among objects taking place in a specific sequence. The sequence takes a certain amount of time to go from start to the end of operation. The sequence diagram generally indicates schedule of different tasks performed and the entity performing the task in a given time-step. For building the Limbukha model, the base sequence was constructed using lessons learned from RPG (Figures 39 and 40). Here, one time step is equivalent to 1 year, each time step is divided into two cycles. The step-by-step tasks are listed as follows:

<u>Cycle 1</u>

1. All farmers decide on the crop succession based on the rainfall and market status.
2. Market price is updated to inform on the last year's market state.
3. Rainfall is initiated for the first cycle (January to mid June).
4. The information on rainfall pattern in given to the villages. At village level water is updated and allocated to each farmer based on his or her category and rainfall pattern. Each farmer calculates his water needs and exchanges with other farmers.
5. Limbukha Farmers only plant potato in their plots (maximum of 3 plots per farmer).

6. Farmers of both villages plant rice.
7. Limbukha Farmers whoever planted potato (in step 5) are activated to harvest (remove) potato and update their plots as fallow. In the same sequence they sell their potato harvest and update their incomes.

Cycle 2

8. Rainfall is initiated for the second cycle (mid June to December).
9. The information on rainfall pattern in given to villages. At village level water is updated and allocated to each farmer based on his or her category and rainfall pattern. Each farmer calculates his/her water needs and exchanges with other farmers.
10. Farmers from both villages are activated to plant rice.
11. Farmers from both villages harvest (remove) rice and update their plots/block as empty. In the same sequence they sell their harvest rice and update their income.

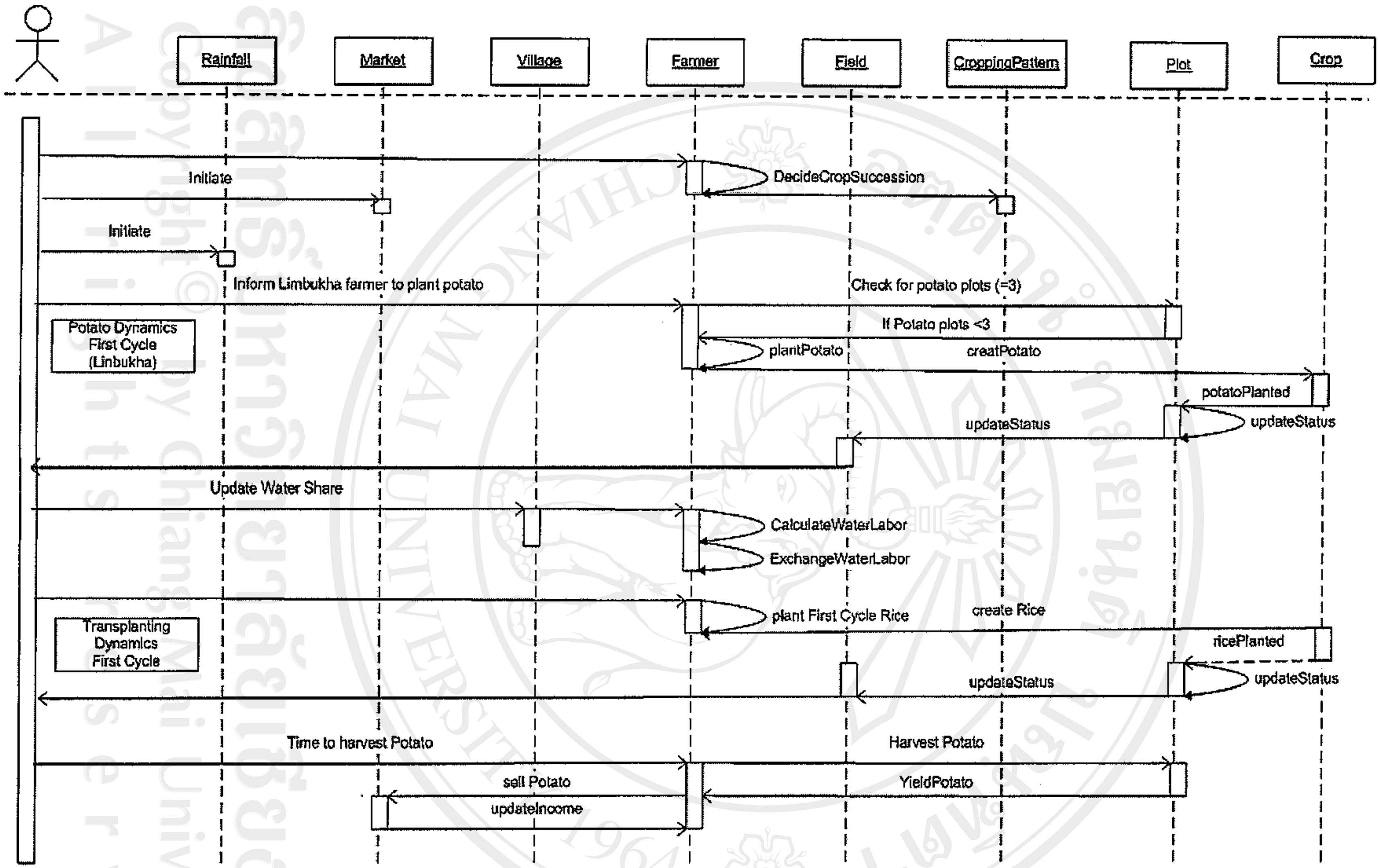


Figure 39. Sequence diagram of Limbukha model (Cycle1 corresponding to January to mid-June).

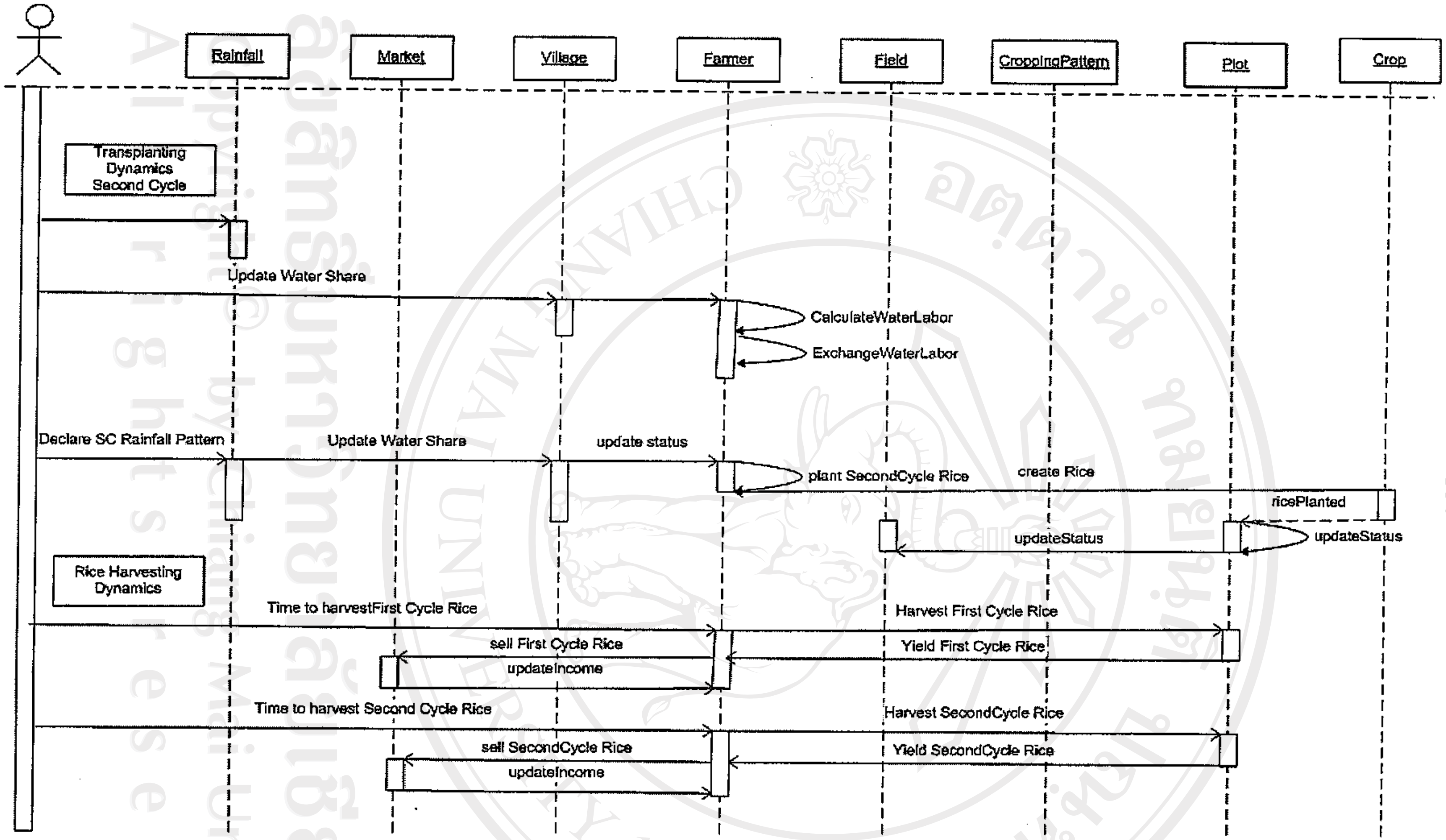


Figure 40. Sequence diagram of Limbukha model (Cycle 2 corresponding mid-June to December).

6.4 Data integration

Programming was done in CORMAS 2003. The codes used in Limbukha model are given in Appendix 1. The artificial environment was designed to represent plots and blocks of plots assigned to 12 farmers. For the synthetic environment an interface of 8 x 13 grid size was used (Figure 41). It was like placing two game boards (one for Limbukha and other for Dompola) used in Dompola RPG side by side. This was done to mainly maintain similarity to the game so that players will be familiar with the visualization when the model will be used to discuss the simulation outputs. Field 1-6 represents Limbukha while 7-12 represents Dompola. The allocation of fields and plots to different water sharing category is shown in Table 22. The parameters used in the base model came from both the diagnostic study and the RPG.

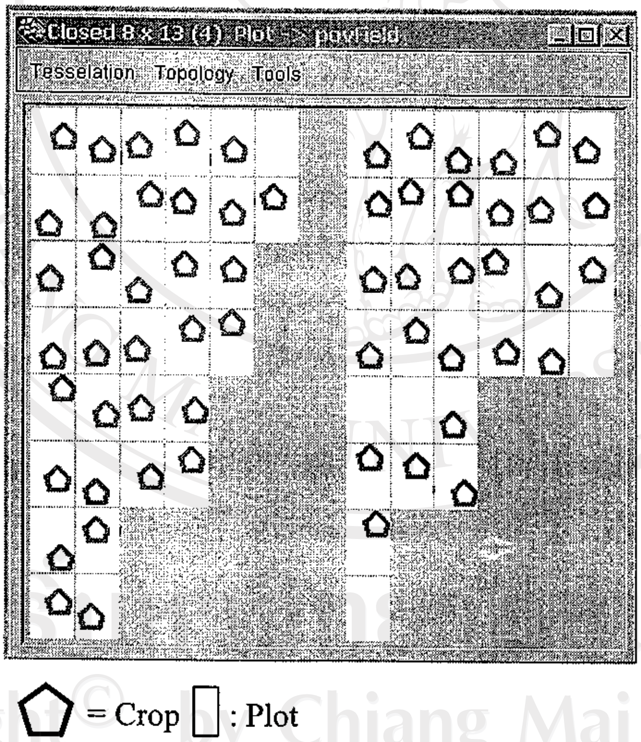


Figure 41. The artificial "Synthetic" environment and main grid interface of the Limbukha model.

Table 22. Allocation of blocks and plots to each communicating agent.

Village	Farmer No.	Water Share Category	Block No.	Total plots
Limbukha	1	Thruelpa	1	8
	2	Thruelpa	2	8
	3	Cheep	3	6
	4	Cheep	4	6
	5	Chatro	5	4
	6	Lhangchu	6	2
Dompola	7	Thruelpa	7	8
	8	Cheep	8	6
	9	Cheep	9	6
	10	Chatro	10	4
	11	Chatro	11	4
	12	Chatro	12	4

Two modes of communication (intra-village and inter-village) were tested. In each time step it was seen that all agents communicate with every agent in the environment. Figure 42 show the exchange of water between farmer 7 and 9; 7 and 10 and 4 and 2. Such interactions were very prominent in every time step.

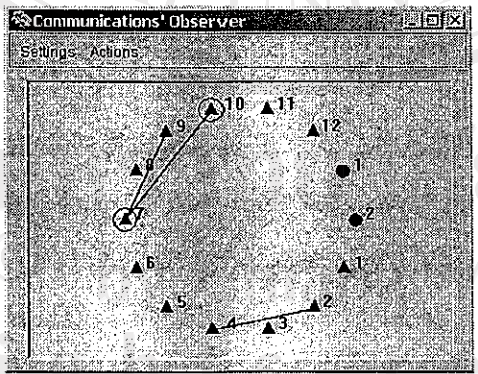


Figure 42. CORMAS Communication observer showing the exchange of water between agents in Limbukha Model (Circle represents communicating agents).

6.5 Checking the model

The scenario closest to reality was chosen to test the consistency of the model outputs. The scenario in which agent first gave water to their kins then followed by exchanges with acquaintances was used for the test run. The steps shown in the sequence diagram of section 6.3.2 were used in the base model. As Manson (2002) suggested, scenarios have been examined from a number of stylized, theoretical perspectives to see if they are qualitatively reasonable. Similarly Bousquet et al. (2002) also indicated that the validation of models could be partly done by interviewing experts. Three simulations of the base model were run to check its consistency and behavior. Each simulation was run over 20 time steps. The outputs of the simulations were captured in Excel spreadsheets and several graphs were generated. While the discussion of simulations with farmers has yet to be done, visual comparison of model outputs with that of RPG were done to assess its consistency.

The simulation outputs shown in Figure 43 indicate the similarity of base model and RPG outputs. At least they behave consistently to changes in parameters. For instance, number of plots planted to rice (Figure 43a) consistently remained within the range of 46 to 66 varying according to rainfall pattern and market states. This corresponds to the sum of rice plots in a year for the two villages in the Dompola RPG (Figure 22).

The number of plots planted to potato in Figure 43b behaved differently from RPG output. The main difference was the absence of potato in some years in the model output, while RPG results show potato being grown every year in Limbukha (Figure 22a). The reason for not having potato was the condition of market price and rainfall pattern used in making the cropping pattern decision in the MAS model. A peculiar behavior of the model was that potato plots varied between 0 and 17, indicating that there could be some weakness in the model in comparison to RPG. In any case it maintained the maximum limits of 17 plots.

Amount of unused water units in the model fluctuate between 2 and 12 depend on rainfall pattern (Figure 43c). It appeared that model over estimates the amount of unused water compared to the RPG output where the maximum numbers of unit of unused water was 6 (Figure 23). This could be due to the protocol which has to be strictly followed in exchanging water in the model. From the way the model behaves, it is considered that it is consistent in terms of its response to the parameters used in the simulations. In case of the number of fallow plots, model indicates a fluctuation between 2 and 18 (Figure 43d) which corresponds to the output of the RPG where it fluctuated between 3 and 14 (Figure 22 and 27). Here the model behaves similarly to RPG.

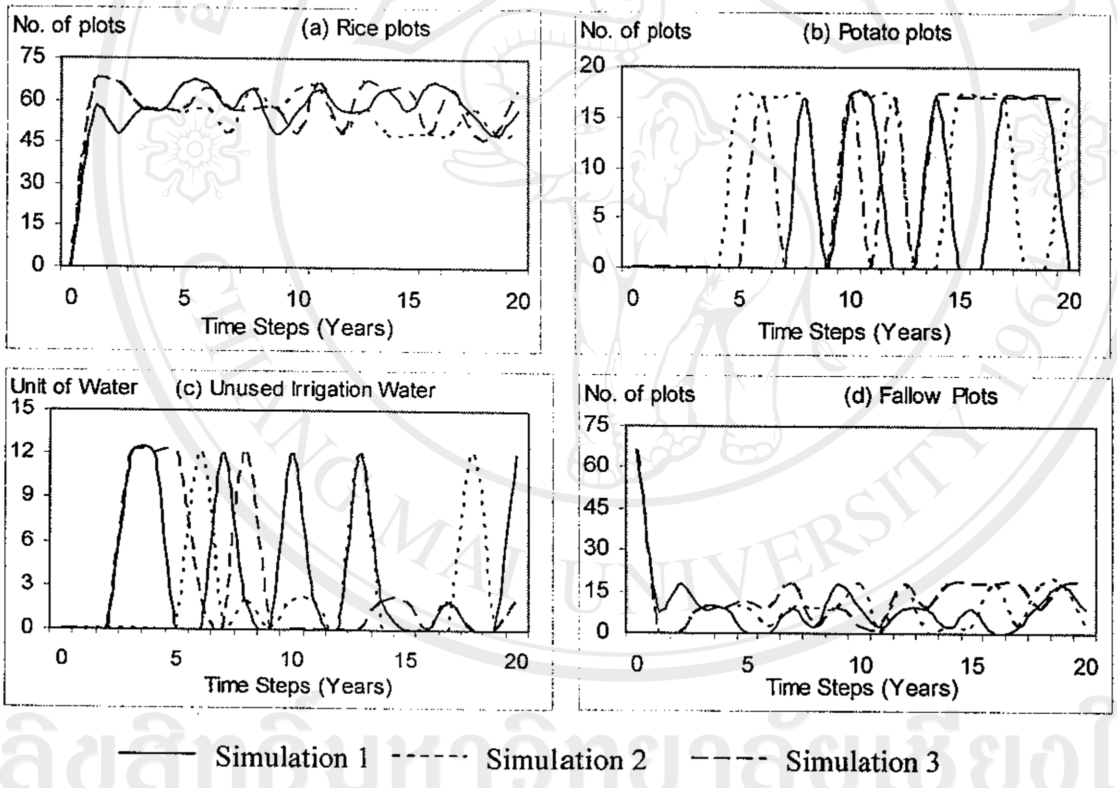


Figure 43. Test of Limbukha base model indicating (a) rice plots, (b) potato plots, (c) unused irrigation water, and (d) fallow plots generated from 3 simulations of the base model.

The total annual income of all the players ranged from US$ 4,000 to 25,000 in the model (Figure 44). The total income fluctuated more than in the RPG, where the net income varied between US$ 7000 and 18000. The wide income fluctuation in the model is linked to a greater variation of the number of potato plots between 0 and 17 in the model.

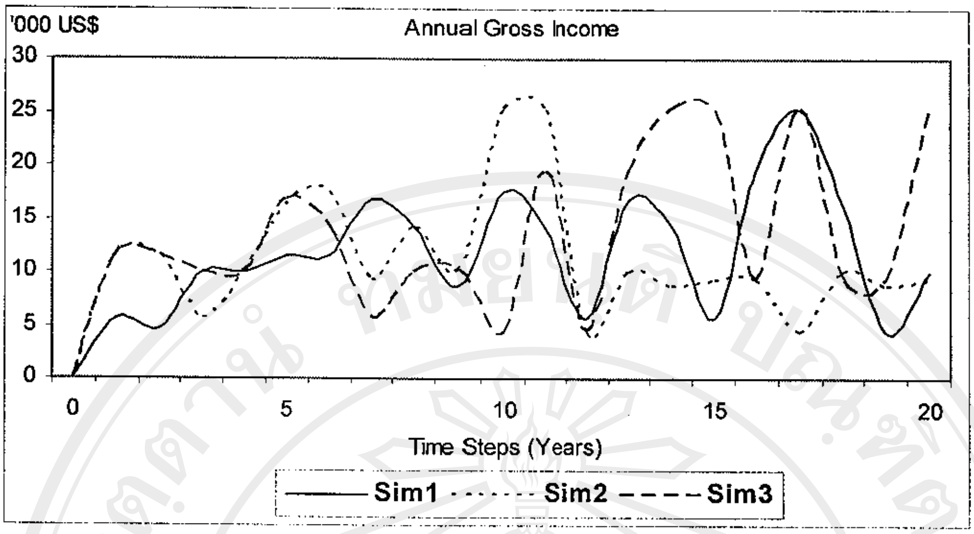


Figure 44. Test of Limbukha base model showing variations in the annual gross income from all players generated from 3 simulations.

In general the Limbukha model represented adequately the RPG except that it behaved differently in the case of potato planting. The variation in income is not a serious issue as its fluctuation is closely related to the number of potato plots. Overall the Limbukha model can be considered to qualitatively and theoretically consistent in representing the RPG. However, as part of the companion modeling approach, the model verification should be done in consultation with other experts, stakeholders, and policy makers. Considering the present state of the model, it can be used for a explorative comparative study of different scenarios.

6.6 Scenarios

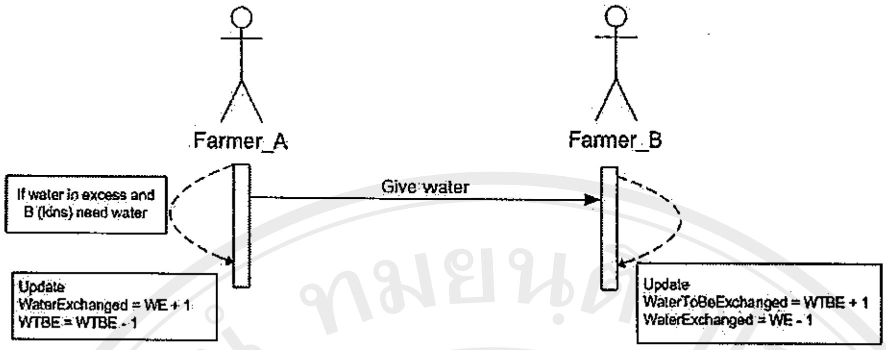
As Limbukha model was roughly able to represent the RPG it was used to generate scenarios to understand the potential effects of changes in strategies on the resource and the economic returns of irrigators. To generate multiple scenarios, three main parameters; namely social networks, rainfall patterns and exchange protocols, were identified (Table 23). Accordingly, 36 scenarios with 20 runs per scenario were produced. Data from each scenario were captured in Excel spreadsheet and the average data of 5 variables are presented in Appendix 3.

Table 23. Possible scenarios to be simulated with the Limbukha model.

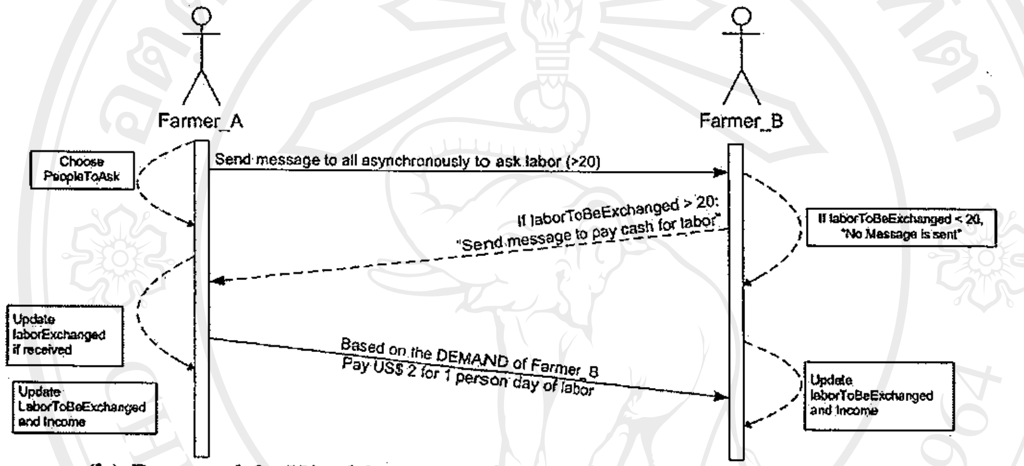
Parameters	Variables
Social network	N_1: Kinship (Table17)
	N_2: Among all members of same village (N1 + acquaintances in the same village)
	N_3: Among members of both the villages (N1 + acquaintances in both villages)
Rainfall pattern	R_1: Dominantly Low (Refer to appendix 2)
	R_2: Dominantly High (Refer to appendix 2)
Protocol	P_1: Give water to kinship (Figure 45a)
	P_2: Exchange water against labor or cash (Figure 38)
	P_3: N1 + Exchange labor against cash (Figure 45b)
	P_4: Exchange water free of charge
	P_5: Exchange labor against water (Figure 45c)
	P_6: $P_1 + P_2 + P_5$

The 36 scenarios were further classified based on their fulfillment of 6 criteria. The classification was necessarily used to categorize and identify potentially viable scenarios which can be further discussed with farmers. Threshold for each indicator were based on researcher's perception of the situation, for instance the minimum number of plots planted to rice should be 12; fallow plots should not be more than 7; there should be at least 6 potato plots; at least there should be 1 instance of exchange of unused water which total should be less than 3 units; and finally the total annual income should be more than US$ 10,000. Use of such indicators refined with stakeholders can facilitate a collective discussion and learning. In the real situation, thresholds can be identified by stakeholders to classify scenarios more realistically according to their perceptions.

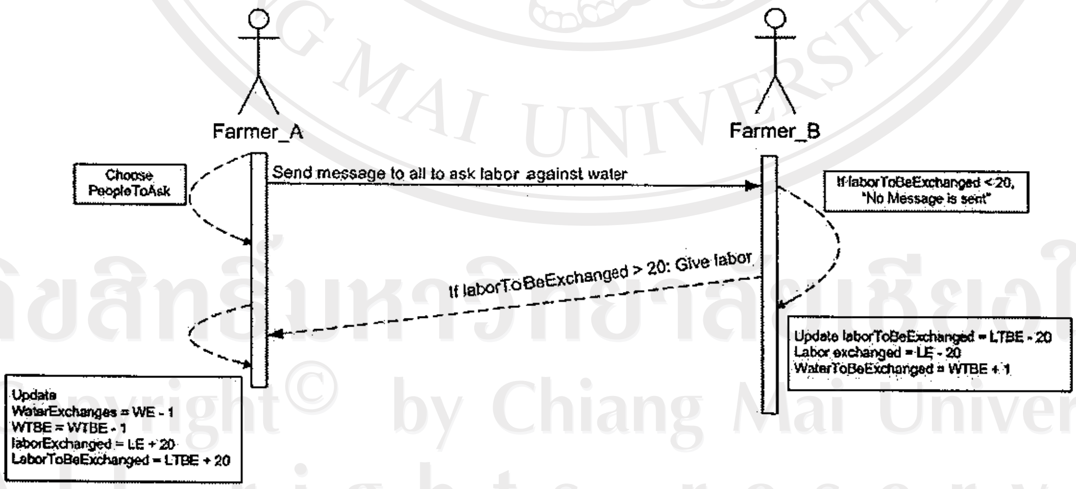
In all 36 cases, communication among agents occurred which could be seen on the "Communication Observer" visualization window of CORMAS. Out of the 36 scenarios, agents exchanged labor in 9 scenarios. The result indicated that, labor exchange was highest in exchange protocol P3 and P5. In case of water exchange in 7 scenarios social network played a major role, the result showed that N3 (Kinship + acquaintance in both villages) promoted water exchange.



(a) Protocol 1: Give water to kinship



(b) Protocol 3: Kinship network + exchange labor against cash.



(c) Protocol 5: Exchange labor against water

Figure 45. Protocols (a) P1, (b) P3, and (c) P5 used for scenario analysis in the Limbukha model.

Three measures of viability: high, medium and low were used to assess the scenarios for further exploration. A scenario was considered highly viable if it fulfilled more than five criteria and conditions displayed in Table 24. Similarly they were categorized as medium or low if they fulfilled 3-4 criteria and conditions or less than 2 criteria respectively.

Table 24. Classification of scenarios based on thresholds of six criteria and conditions.

Unused irrigation water *(< 3 units)*	Fallow plots *(< 7 plots)*	Potato plots *(> 6 plots)*	Rice plots *(> 12 plots)*	Annual income *(> US$ 10,000)*	Water exchange *(>1 transaction)*
112, 113, 122, 123, 213, 215, 216, 222, 223, 224, 225, 226, 313, 315, 316, 322, 323, 324, 325, 326	111, 114, 115, 116, 124, 126, 213, 214, 223, 226, 311, 313, 323	112, 113, 114, 115, 116, 121, 122, 125, 126, 211, 212, 213, 214, 215, 221, 222, 223, 224, 225, 311, 312, 313, 314, 315, 321, 322, 323, 324, 325, 326	All Scenarios (as minimum number of plot is 43)	111, 114, 115, 116, 121, 124, 125, 211, 212, 213, 214, 223, 226, 311, 312, 313, 314, 321, 322	212, 222, 312, 313, 314, 322, 323

N.B: 111 = First digit represent Social network (1, 2, 3); second digit represents rainfall (1 and 2); and third digit represents Protocol (1 to 6).

The results summarized in Table 25 show that 71% of the scenarios displayed viability medium. Majority of the scenarios based on interactions among kinship only are medium viable and there are no highly viable scenario. Interactions among kinship and acquaintances within and between villages resulted in 6% and 8% scenarios fulfilling more than 5 criteria respectively. It further validates the finding of the RPG that a collective communication mode facilitates a better resource use and also fulfills other socio-economic objectives. Overall, it can be seen that only 14% of the scenarios were highly viable, while 15% of them showed low viability. These variations can be due to the criteria and associated conditions in the classification. However, this result needs further discussion with the stakeholders to draw concrete conclusions.

Table 25. Proportion (%) of scenarios under different levels of viability range based on three types of social networks.

Network	Viability of scenario*			Total
	High	Medium	Low	
Kinship	0	27	6	33
Kinship and acquaintances within village	6	22	6	34
Kinship and acquaintances of two villages	8	22	3	33
Total	14	71	15	

* High = satisfies 5 indicators; Medium = satisfies 3 to 4 indicators; and Low = satisfies less than 2 indicators. Indicators are presented in Table 21.

Interdependences of parameter

Networks and protocols were classified into two income categories and three land use types. The non significant result in Table 26 indicates that income levels did not depend on social networks. Further more income levels were not dependent on exchange protocols (Table 27). However, it was the kinship network and the exchange protocol within kinship that gave a higher income compared to other protocols.

Table 26. Frequency of scenarios for test of independence between social network and income categories.

Social network	Annual income levels* (US$)		Total
	<10,000	>10,000	
Kinship	4	8	12
Kinship and acquaintances within village	6	6	12
Kinship and acquaintances of two villages	6	6	12
Total number of scenarios	16	20	36

*: Annual income implies the collective income of both villages.

Table 27. Frequency of scenarios for test of independence between exchange protocols and income categories.

Exchange protocols	Income levels (US$)		Total
	<10,000	>10,000	
P_1: Give water to kinship	1	5	6
P_2: Exchange water against labor and cash	4	2	6
P_3: Exchange water with kinship and Exchange labor against cash	2	4	6
P_4: Exchange water free of charge	2	4	6
P_5: Exchange labor against water	4	2	6
P_6: $P_1 + P_2 + P_5$	3	3	6
Total of scenarios	15	21	36

Similarly, a test of independence was also done to see the relationship between land use decisions, kinship and protocol. The results clearly indicate the independent relation between land use types and social network class (Table 28). As in the case of independence of income on protocol, there is evidence of the independence of land use types to exchange protocol (Table 29).

These results can be a point of discussion among the stakeholders. In no circumstances the result implies or predicts a definite goal; however it presents the option for discussion, a way forward.

Table 28. Frequency of plots for test of independence between social network and land use categories.

Social network	Land use types			Total
	Potato	Rice	Fallow	
Kinship	8	55	11	74
Kinship and acquaintances within village	8	53	13	74
Kinship and acquaintances of two villages	9	51	14	74
Total	25	159	38	222

Table 29. Frequency of plots for test of independence between exchange protocols and land use categories.

Exchange protocol	Land use types			Total
	Potato	Rice	Fallow	
P_1: Exchange water only with kinship	9	56	10	75
P_2: Exchange water against labor and cash	9	48	18	75
P_3: Exchange water with kinship and Exchange labor against cash	9	58	8	75
P_4: Exchange water free of charge	8	52	14	74
P_5: Exchange labor against water	8	48	18	74
P_6: $P_1 + P_2 + P_5$	7	55	11	73
Total of scenarios	50	317	79	446

Presentation of in-depth observations

Six scenarios were selected based on the classification of 36 scenarios to investigate their performance. Among them, 2 represent kinship network from medium viable scenarios; 2 were the scenarios classified as highly viable from kinship and acquaintances within village network, and the last 2 were among the highly viable scenarios from two-village network.

Table 30. Description of six selected scenarios from Limbukha model.

Scenario	Parameters	Description of scenarios
S_1	$N_1R_1P_4$	Agents can communicate within kinship network of each village. Agent gives unused water to their kins and to their acquaintances free of charge. The rainfall pattern is low.
S_2	$N_1R_1P_5$	Agents can communicate within kinship network and exchange labor against water. The rainfall pattern is low.
S_3	$N_2R_1P_3$	Agent communicates freely within ones village (Kins + Acquaintances), while they give unused water to kins only; they can buy labor from kins as well as acquaintances. Rainfall pattern in low.
S_4	$N_2R_2P_3$	Agent communicates freely within ones village (Kins + Acquaintances), while they give unused water to kins only; they can buy labor from kins as well as acquaintances. Rainfall pattern in high.
S_5	$N_3R_1P_3$	It is a full network, where agent communicates freely among all agents of both the villages. They give unused water to kins only and buy labor from kins as well as acquaintances. Rainfall pattern in low.
S_6	$N_3R_2P_3$	It is a full network, where agent communicates freely among all agents of both the villages. They give unused water to kins only and buy labor from kins as well as acquaintances. Rainfall pattern in high.

The six scenarios were compared using 5 criteria and associated conditions (Unused irrigation water < *3 units;* fallow plots < *7 plots;* rice plots > *12 plots;* annual income > *US$ 10,000;* and water exchanged >*1 transaction).* In terms of unused water Figure 46 shows that S_1 and S_2 which represents interaction among kinship results in unused irrigation water ranging between 6 to 8 units, while it was less than 2 units for other scenarios. In S_5 and S_6 there is hardly any water left as unused. It indicates that kinship network alone is not enough for efficient sharing of water. In Figure 47 it is clear that water is exchanged only in S_5 and S_6. As the exchange between kin is free, it is not accounted as water exchanged.

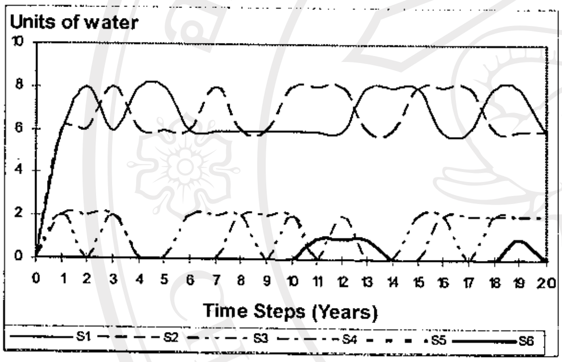


Figure 46. Units of unused water under 6 scenarios simulated by the Limbukha model.

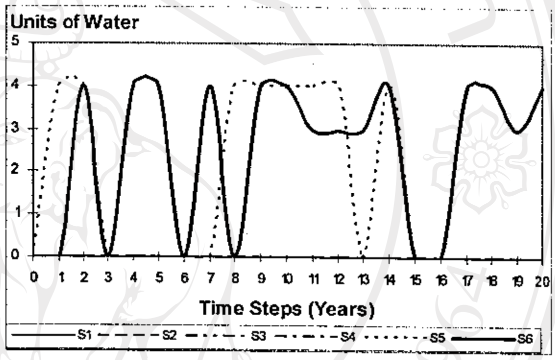


Figure 47. Units of water exchanged under 6 scenarios simulated by the Limbukha model.

In all the six scenarios plots planted to rice ranged between 58 and 66. On average, S_3 to S_6 resulted in more than 64 plots being planted, while only 60 plots were planted to rice in S_1 and S_2 (Figure 48). Correspondingly, the number of fallow plots was higher in S_1 and S_2 (Figure 49). On an average, S_3 and S_4 resulted in 1 fallow plot. It indicates that network within the village ensures minimizing fallow plots.

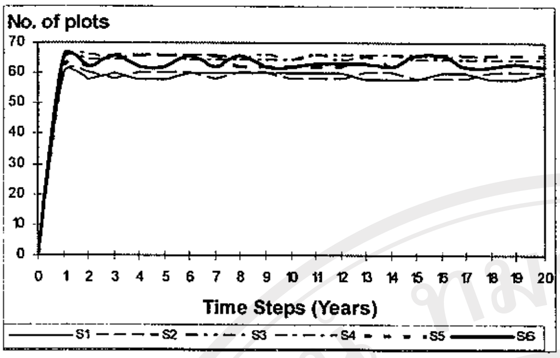


Figure 48. Number of plots planted with rice under 6 scenarios simulated by the Limbukha model.

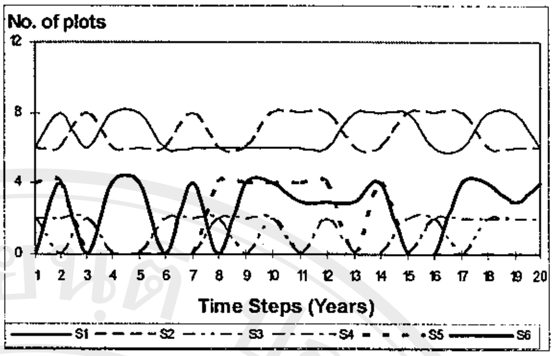


Figure 49. Number of fallow plots under 6 scenarios simulated by the Limbukha model.

The variation in annual income among the six scenarios ranged from US$ 10,000 to 25,000 (Figure 50), which is greater than the fluctuation, registered in RPG, where income ranged from US$ 7,000 to 10,000. Generally S_6 resulted in the highest income with lesser variation over the years. Result also showed that the lowest incomes were observed in the case of S_1 and S_2 with the highest variation of 32%. This indicates that kinship network extended to both villages and protocols allowing exchange between villages could ensure higher average incomes over the years.

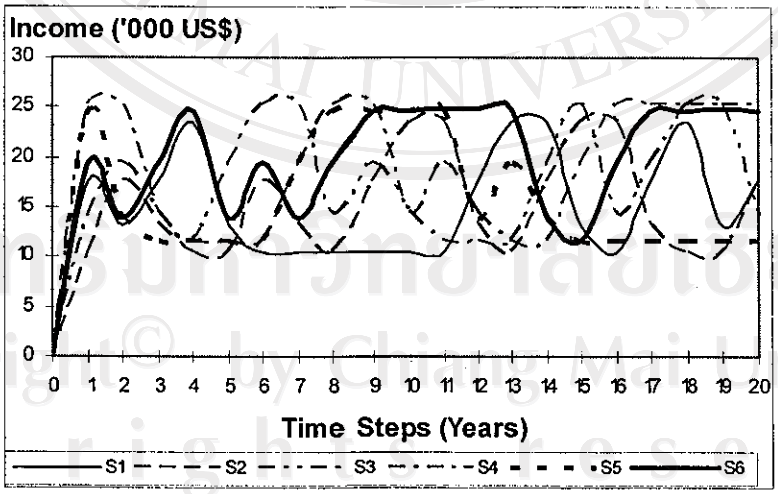


Figure 50. Annual income of 12 farmers generated from the six scenarios Limbukha model

6.7 Discussion

The experimentation with the Limbukha model provided some valuable insight in the resource use dynamics. As the stakeholders have not validated the model yet, the outputs can be considered as tentative results that can help to reorienting the next step of the process. The results consistently indicated that social network extended to both villages (N3) associated with P6 provided a better option to use resources and produced higher incomes more specifically, from the analysis of selected viable scenarios, the results showed that scenarios with kinship network led to more unused water, higher fallow plots, and no instance of exchange. Even in the case of number of rice plots, the kinship network was not as efficient as exchange protocols.

In relation to the interactions (communication) among agents, the kinship network produced maximum interactions among agents to exchange irrigation water. It may be due to the fact that water is first given free of cost to kins. In contrast, exchange of messages (interactions) for labor exchanges was highest under protocols where labor is exchanged against water. These indications justify a need for detailed analysis and understanding of the exchange protocols and social network in resource management.

The Limbukha model was able to integrate information and simulate scenarios that can be used to discuss and communicate the issue of water sharing with stakeholders. For example, the categories of viable scenarios generated from the Limbukha model can now be used as tools to generate discussion and collective learning among the stakeholders in the field.