N^{o} d'ordre Année 2010

THESE DE L'UNIVERSAITE DE LYON

Délivrée par

L'UNIVERSITÉ CLAUDE BERNARD LYON 1

ECOLE DOCTORALE Evolution, Ecosystèmes, Microbiologie, Modélisation

DIPLOME DE DOCTORAT

(arrêté du 7 août 2006)

Soutenue publiquement le 26 Mai 2010

Par

PROMBUROM Panomsak

<u>TITRE</u> : Companion modeling & watershed management in Northern Thailand:
The importance of local networks

Directeur de thèse: François Bousquet (Cirad)

JURY: Andreas Neef (Kyushu University, Japon) Rapporteur
Olivier Barreteau (Cemagref) Rapporteur
Alain Pavé (CNRS-Université de Lyon 1) Examinateur
Benchaphun Ekasingh (Chiang Mai University, Thaïlande) Examinateur

ACKNOWLEDGEMENTS

First of all I would like to express deep gratitude to Dr.François Bousquet, my Ph.D. thesis director from the CIRAD-GREEN research unit, who made this thesis possible. He always patiently gave me advises and motivation along the long period of my thesis work. I also would like to extend my gratitude to all the friends in this research unit, who provided me suggestions and help during the stay and study in France, until the last day before the thesis defense. I would like also to thank Jean-Pierre Flandrois, Directeur de l'Ecole Doctorale E2M2, l'Université Claude Bernard Lyon 1, who provided me the administrative supports in enrolling the Ph.D. program. I would also give my sincere thanks to all the examining committee from abroad Dr.Andreas Neef (Kyushu University, Jan), Dr.Olivier Barreteau (Cemagref) and Dr.Alain Pavé (CNRS-Université de Lyon 1).

I would like to express my deeply thanks to the Multiple Cropping Center (MCC), Chiang Mai University (CMU), Chiang Mai, Thailand; the research institute I worked with before starting the Ph.D. thesis. The MCC, through the authorization from the CMU, allowed me to leave for the study and continue my work after completion of my Ph.D. This would not have been possible without the support from the two previous heads of the MCC; I would like to express my gratitude to Phrek Gypmantasiri and Dr.Methi Ekasingh, who provided me this great opportunity, motivated me to pursue higher education abroad to gain invaluable professional knowledge and experience. I would like to thank the Ford Foundation who granted me the Ph.D. scholarship during the first period. The last person from the MCC that I would like to express my thanks to is Dr.Benchaphun Ekasingh, the current head of the MCC who continuely supported my thesis work, and devote her valuable efforts for being my Ph.D. defense committee.

I am indebted to many of people in the Maehae watershed, my study area; who had to leave the "always busy work" in the field or even the relax time after hard work to participate numbers of research activities. Moreover, trust and friendship are invaluable things I received from them. My thanks also go to the Maehae development center, the Royal Project Foundation who provided me room to stay during the field work.

Lastly, I would like to thank the CPWF-PN25 project funded by the CGIAR that provided me the Ph.D. grant during 2006-2009 period; and the Franco-Thai, French Embassy who offered me partial allowance support during the stay in France.

Panomsak Promburom

26 May 2010

ABSTRACT

In the northern watershed area of Thailand, the increase in watershed resources degradation due to the combination of population and economic growths led to diverse controls and responsible agents. Thai government has put substantial effort to empower and involve local people in resource governance, to eradicate the problem and mitigate the conflict of interest. However, the people participation does not progress beyond informative and consultative levels. The Maehae is one of the complex watershed management cases where intensive vegetable cultivated lands located in restricted watershed area, multi-level stakeholders involved in watershed resources management existed.

To promote good resource governance, the research questions proposed here is how to employ companion modeling (ComMod) process and mediating tools to promote mutual and adaptive learning among stakeholders to enhance collective watershed management. The main field research methods implemented in this study are role-playing game (RPG), stakeholders observation and multi-agent based model (MABM).

Preliminary system analysis of the Maehae revealed a potential conflict among the farmers and the forester. Two land-forest role-playing game (RPG) sessions were conducted in order to gain a better understanding on how these stakeholders use and manage land and forest under conflict of interests. The games showed that farmers and forester could negotiate to collectively conserve forest area at the satisfactory level.

The severe drought occurred in late 2004 became a critical concern, some farmers trespassed the head-water area to get better water access. Due to the first-come, first-served water management, this affected the down-stream farmers. The water management RPG was conducted to observe how farmers would respond to the water shortage situation. The game players collectively agreed on limiting cultivated land to achieve equal water sharing. They expressed the need for the similar concert effort organized among all villages in the Maehae.

The village network established among all 14 villages in the Maehae was found an important local institution interfacing with the forester in managing this conflict of interest. The researcher regularly attended the monthly meetings of the VN to observe its functioning regard to forest encroachment and water shortage problems. In general, the farmer may found the new farm plot in the forbidden area and may report to the village network. The village network would investigate the case, negotiate with the plot owner and finally withdraw the plot with penalty. This takes long time and might not be accomplished. There are four factors contribute to functioning and performance of the village network which are monitoring (Mon), social network (Soc), strength of the village network committee (VN), penalty or sanction (San) and lobby (Lob) for voting against the case.

Regarding the water shortage and water use conflict problem, the village network, all the village committees, forester and the higher administrative organizations joint together in problem analysis and formulating management measures. This effort among multi-institutional levels took more than two years to achieve an agreement on limiting irrigating pipe size in the upstream area.

The knowledge and findings derived from the RPGs and stakeholders observation were integrated into a Multi-Agent Based Model (MABM) design and development using Cormas platform. The model represents key actors involved at an individual and institutional level (farmer, village network, and forester); includes farmland, forest and water resources. The individual farmer can observe, communicate with others to disseminate information to the village network concerning the new plot creation and water shortage problem. The main features of the model emphasize the behavior and the decision-making of the farmers on using the resources and managing farm land, as well as the actions and interactions taking place between the individuals and the village network. It therefore focuses on a detailed representation of the village network function and decision-making process.

There were different scenarios formulated from the previous multi-level stakeholder's engagement were simulated. The indicators, as outputs from the model simulation reflected the key performances of the system, which were water availability, forest disturbance, farm productivity, economic revenue and the equitability of income distribution. The "business as usual" scenario simulation represents the existing land and water management of the Maehae, creating new plot strategy cannot solve the water shortage problem but rather to distribute the problem to all. The "limiting pipe size" scenario illustrates the gradual eradication of the water shortage problem through the creation of water use regulation.

A sensitivity analysis was conducted to assess the influences of the five factors (Mon, Soc, VN, Lob, San) to the village network function. This scenarios exploration showed that the San was only determinant factor in the "business as usual" scenarios. The San increased total cash income but widened income distribution gap; it could reduce forest disturbance and promoted total farm productivity. The "limiting pipe size" scenario simulation suggested that strengthening of the village network function and individual engagement in the development and monitoring of water rules are important. Thus, VN, Lob and San are co-determinant factors.

In summary, The Maehae village network, as the local network, bridges diverse ties both ethnicities and communities. It links individual, groups and higher policy network; performs as intermediary informal political network to co-manage the watershed resources and mitigate possible tensions among stakeholders. The village network function represents a cultural evolution process through social learning and gaining of environmental concerns, therefore, enhances adaptive capacity and increase resilience.

This study opens the black box of the Maehae village network functioning which is strongly linked to the individual action that helps examining the ways the dynamics of institutional arrangements constrain or enhance the resource governance performance; through the model and scenarios exploration. The study recommends the important of key stakeholders' involvement, the trust between researcher and the stakeholders, the neutral position of the researcher. Further stage of companion modeling would be required, to share collective local management plan with larger interconnected policy networks, through the model simulation, and move to further co-planning and co-decision making for sustainable watershed resource governance.

RÉSUMÉ

Dans la zone nord des bassins versants de la Thaïlande, l'augmentation de la dégradation des ressources du bassin hydrographique résultant de la combinaison de l’augmentation de la population et de la croissance économique ont conduit à la création de contrôles divers par différents agents. Le gouvernement thaïlandais a fait des efforts considérables pour responsabiliser et impliquer les populations locales dans la gouvernance des ressources, pour éradiquer le problème et atténuer les conflits d'intérêts. Toutefois, la participation de la population ne progresse pas au-delà des niveaux d'information et de consultation.

Afin de promouvoir la bonne gouvernance des ressources, la question de recherche proposée ici est de savoir comment utiliser la modélisation d'accompagnement (ComMod) qui est un processus de médiation outillé pour promouvoir la compréhension mutuelle et l'apprentissage adaptatif chez les intervenants afin d’améliorer la gestion collective des bassins versants. Les principales méthodes de recherche mises en œuvre dans cette étude sont le jeu de rôle (RPG), l'observation participante et la modélisation multi-agents. L'analyse préliminaire du cas du bassin versant Maehae a révélé un risque de conflit entre les agriculteurs et les forestiers. Deux sessions de jeu de rôle (RPG) ont été menées afin de mieux comprendre comment ces acteurs utilisent et gèrent des terres et des forêts malgré des conflit d'intérêts. Les jeux ont montré que les agriculteurs et les forestiers peuvent négocier collectivement et conserver la superficie forestière à un niveau satisfaisant.

La grave sécheresse survenue à la fin 2004 est devenue une préoccupation essentielle, certains agriculteurs ayant accédé à l’amont du bassin versant pour obtenir un meilleur accès à l'eau. En raison de la règle "premier arrivé, premier servi », cela a affecté les agriculteurs en aval. Le jeu de rôle sur la gestion de l'eau a été mené pour observer la façon dont les agriculteurs font face à la situation de pénurie d'eau. Les joueurs se sont mis collectivement d'accord sur la limitation des terres cultivées pour atteindre l'égalité de partage de l'eau. Ils ont exprimé la nécessité d’un effort concerté entre tous les villages du bassin versant de Maehae.

Le réseau villageois établi entre tous les 14 villages de la Maehae a été révélé comme une importante institution locale pour l’interfaçage avec le forestier dans la gestion de ce conflit d'intérêts. Le chercheur a participé régulièrement aux réunions mensuelles du réseau villageois pour observer son fonctionnement à propos de l'empiètement sur les forêts et des problèmes de pénurie d'eau. Le modèle est le suivant : l'agriculteur peut observer une nouvelle parcelle dans la zone interdite et peut en faire état au réseau villageois. Le réseau villageois enquête sur l'affaire, négocie avec le propriétaire de la parcelle et enfin retire la parcelle avec sanction.. Il existe quatre facteurs qui contribuent au bon fonctionnement et la performance du réseau de village

qui sont la capacité d'observation, le réseau social, la force du comité du réseau du village, le niveau de sanction et la force de lobbying.

En ce qui concerne la pénurie d'eau et le problème des conflits d'utilisation de l'eau, le réseau villageois, tous les comités de village, le forestier et les organismes administratifs supérieurs commune sont parties prenantes. Cet effort entre les différents niveaux multi-institutionnel a mis plus de deux ans pour parvenir à un accord sur la limitation des dimensions des tuyaux d'irrigation dans la zone amont.

Les connaissances et les résultats issus de l'observation participante et l'observation des intervenants ont été intégrés dans un modèle multi-agent. La conception et le développement utilisent la plate-forme Cormas. Le modèle représente les principaux acteurs impliqués à un niveau individuel et institutionnel (réseau village fermier, et forestier), inclue les terres agricoles, les forêts et les ressources en eau. L'agriculteur peut observer, communiquer avec d'autres pour diffuser des informations au réseau villageois, concernant la création de nouvelles parcelles et le problème de pénurie d'eau. Les principales caractéristiques du modèle concernent le comportement et la prise de décision des agriculteurs sur l'utilisation des ressources et la gestion des terres agricoles, ainsi que les actions et les interactions qui ont lieu entre les individus et le réseau de village. Il se concentre sur une représentation détaillée de la fonction de réseau villageois et le processus décisionnel.

Différents scénarios ont été formulés à partir de l'engagement des parties prenantes à plusieurs niveaux. Les indicateurs, comme sorties de simulation du modèle reflètent les performances clés du système, qui étaient la disponibilité en eau, la perturbation des forêts, la productivité agricole, les résultats économiques et l'équité de la répartition des revenus. Le scénario de statu quo représente les terres existantes et la gestion de l'eau de Maehae : créer une nouvelle parcelle ne peut pas résoudre le problème de pénurie d'eau, mais plutôt distribue le problème à tous. Le scénario "limitation de la taille des tuyaux" illustre la résolution progressive du problème de pénurie d'eau à travers la création de la régulation des usages de l'eau.

Une analyse de sensibilité a été menée pour évaluer l'influence des cinq facteurs (Mon, Soc, VN, Lob, San) caractérisant le réseau villageois. Cette exploration a montré que la Sanction a été le seul facteur déterminant dans le scénario de statu quo. A sanction augmente le revenu total en espèces, mais élargit les disparités de revenus ; elle pourrait réduire la perturbation des forêts et de promouvoir la productivité agricole totale. Le scénarion "limitation de la taille des tuyaux" suggére que le renforcement de la force du réseau villageois et l'engagement individuel dans le développement et le suivi des règles de l'eau sont importants. Ainsi, VN, Lob et San sont des facteurs déterminants.

En résumé, le réseau villageois, comme le réseau local, crée des liens divers entre deux ethnies et communautés. Il lie des individus, des groupes et des réseaux plus politiques et se pose en tant qu'intermédiaire informel politique pour co-gérer les ressources du bassin hydrographique et atténuer les tensions éventuelles entre les parties prenantes. La fonction du réseau villageois représente un processus d'évolution culturelle par le biais de l'apprentissage social et permet d’accroitre les préoccupations environnementales, et par conséquent, accroît la capacité d'adaptation la résilience.

Cette étude ouvre la boîte noire du fonctionnement du réseau villageois. L'étude souligne l'importance de la participation des principales parties prenantes, la confiance entre le chercheur et les acteurs, la position neutre du chercheur. La prochaine étape dans la modélisation d'accompagnement serait nécessaire, pour partager le plan de gestion collective locale avec les réseaux politiques plus interconnectés, grâce à la simulation du modèle, et passer à d'autres co-planifications et co-décisions en matière de gouvernance durable des ressources des bassins versants.

CONTENTS

FIGURES

TABLES

Chapter 1: INTRODUCTION

1.1 Overview of Watershed Management

1.1.1 General Overview

A watershed is an extent of basin-like landform defined by highpoints and ridgelines that descend into lower elevations and stream valleys. Other terms that are used to describe a drainage basin are catchment, catchment area, catchment basin, drainage area, river basin and water basin. A watershed collects water from the precipitation and channeled downhill into soil, groundwater and a water body such as creek and stream, making its way to larger rivers and eventually the sea. Drainage basins drain into other drainage basins in a hierarchical pattern, with smaller sub-drainage basins combining into larger drainage basins. Watersheds come in all shapes and sizes (Figure 1.1). They cross political and even national boundaries. The important thing about watersheds is: what we do on the land affects water quantity and quality for all communities living downstream. Water movement and water discharge through surface and underground, from the watershed are determined by topography, shape, soil type and land use or vegetation cover factors.

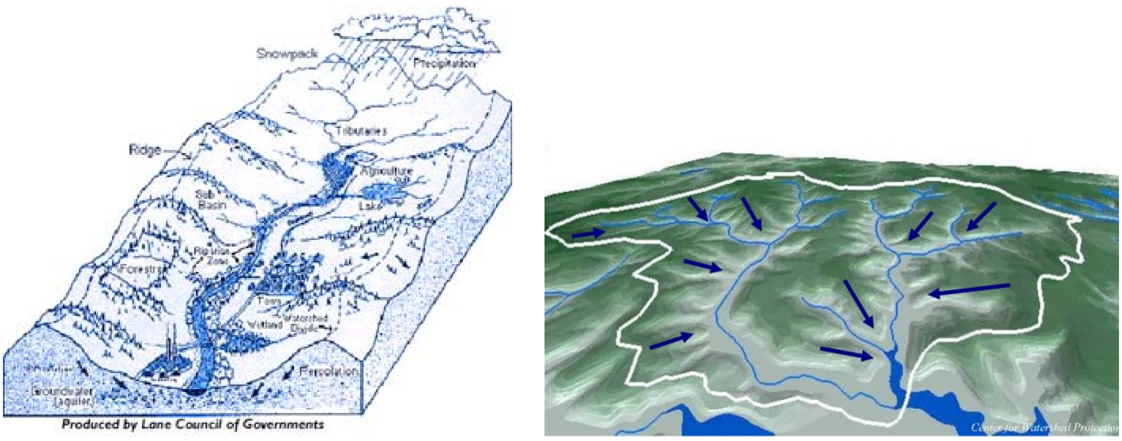


Figure 1.1: Imagined watershed or drainage basin.
Source: (http://www.epa.gov/owow/watershed/what.html,
http://www.cwp.org/Resource_Library/Why_Watersheds/

Watershed is an area-based approach that focuses on the context within a logical drainage basin. Thus, multiple actors see the approach as a mean to accomplish disparate objectives which has resulted in multiple visions of the “watershed approach” (German et al., 2007). Agronomist may aim at suitable crop choice and scaling out technologies (Ekasingh and Ngamsomsuke, 2009); water quality control i.e., nutrient and chemical contamination (Luo and Zhang, 2009; Rao et al., 2009; Makarewicz, 2009). Watershed and forest manager primarily focus in good management of forest resources and mitigate soil erosion (Zhang and Barten, 2009); surface water resource protection (Ferreyra et al., 2008; Seong et al., 2008). Number of studies has been carried out at landscape level to understand and envisage changes in land use and land cover (Bato, 2000; Jessel and Jacobs, 2005; Wakeel et al., 2005).

1.1.2 The Importance of Watersheds

There are various services that human and societies require from watersheds (good quality drinking water, sufficient and stable water amount for agricultural and domestic usage, nice place for recreation purposes, or as an electricity source). Watersheds are important as the viability of the watershed directly affects the health of the communities within it. Water for human consumption, wildlife, industry and recreation are all impacted by activities that occur within the watershed. Fresh water is expected to become the most limiting resources and one of our most precious resources in many parts of the world in present and the near future. Ecologically, water regulates population growth, influences health and condition of living organisms. Thus changing in quality and quantity of water are important factors that determine healthiness of ecosystem confined within a watershed and the lower drainage basin. Water and other resources are interrelated, the uses and conditions of any natural resource in a watershed may, and likely will, affect the others (Blomquist and Schlager, 2005).

FAO (2006) has stated that watershed ecology is very important for humankind. The world's supply of fresh water depends largely on people's capacity to manage upstream-downstream flows. Food security also largely depends on upland water and sediments. Inappropriate watershed management creates many problems, such as deforestation, improper hillside agricultural practices and overgrazing, all of which may increase runoff, prevent the recharging of upland sources, and generate seasonal torrents that spoil the lowland fields. Badly engineered watersheds may not be able to stand heavy rains, and water courses are also very good vectors for biological and industrial chemical pollution.

Biodiversity is one of the ecological issues related to this; it includes the diversity of ecosystems, species and genes, and the ecological processes that support them. Watersheds, particularly in the headwater areas, have also been the focus of study for conserving natural biodiversity, to ensure the provision of essential economic benefits and services to human society such as food, clothing, shelter, fuel and medicines, as well as ecological factors, all of which play an important role in sustainable development.

Recently, climate change has rapidly become the major concern; numerous ecosystems in all parts of the world are considered precious, fragile and prone to number of changes as a result of the consequences of global warming. Thus, watershed areas are important conservation targets for tackling this global issue. Forests are a major resource, as they hold a huge amount of carbon, absorb carbon dioxide and release oxygen to the atmosphere. They also help maintain and stabilize temperatures and the water cycle provides niches for all kind of ecological zones.

1.1.3 Complexity of Watershed Management

In general, watershed boundaries are ‘natural’; their existence as a natural boundary distinguishes them from other human-created borders. Once human beings arrive on the scene and begin interacting with these natural phenomena, watershed boundaries are not defined solely by nature. Throughout the world and for centuries, human beings have been impounding watercourses, transporting water across significant distances, and otherwise altering nature’s design, connecting waters previously not regarded a part of the same watershed (Blomquist and Schlager, 2005).

Forests, one of the most valuable resources in a watershed, have always been targeted and transformed by humans to serve their desires; for recreation purposes, as a source of economic value, as ecological niches and for carbon stock, among other activities. Lumber logging has been used to drive economic growth and development at the national and international levels, for example, as in Myanmar and Thailand over the past century (Isager, 2001; Pragtong and Thomas, 1990) and across the huge Amazon rainforest area which has been depleted for similar purposes. Furthermore, the increased human population and food demand has caused forest encroachment and the conversion of forests to agricultural land, activities that have drastically affected and altered the fragile and complex watershed ecosystems.

Crop cultivation depends completely on water and nowadays it demands significant inputs, especially of chemical agents, to ensure a good crop yield. In general, these inputs are not completely utilized by the crops; the residuals are stored in the soil layers and leach out into streams and rivers. This causes chemical contamination and pollution of the water table, something that affects the quality of water required for other downstream uses. Furthermore, inappropriate cultivation practices, particularly in sloping areas, denude the soil surface; contribute to water runoff, soil fertility degradation, soil erosion, as well as sedimentation in reservoirs.

Therefore, watersheds are not only providing services to a multitude of users, but also venues for conflicts of interest. Resource scarcity leads to increased competition among users; continuous resource deterioration prompts relevant agencies to seek proper governance. As a result, a variety of management techniques and measures have been imposed on watershed areas by the different types of agencies involved; however, some of the work of these organizations can be compromised and they do not always get along with one another; quite often, some of the goals and implementation activities disturb and/or distort those of other agencies. There are various efforts and regulations imposed on watershed areas, though the objectives proposed may be reasonable and well accepted. However, it is difficult to balance all of the expected outcomes with regard to human well-being, food security, fairness, economic development and sustainable resource use.

Natural resource conservation efforts, through the implementation of regulations concerning land, forest and water resources, are pushing ahead watershed areas as relevant spaces for resource management. However, this has created difficulties in practice, since resources are often shared across two or more drainage basins, and connections may exist between many neighboring basins. Thus, a watershed management regime may be unable to define an absolute target space; the manager involved may have to extend the scale of concern across a pre-defined territory, due to a trans-boundary context. Such a watershed boundary originally defined using the natural contours, may be overlaid and mismatch with other virtual territories that create distinctly different management schemes imposed on the responsible areas, such as an official political boundary, traditional or customary boundaries or a forest protection area. This creates complexity in terms of managing a watershed, as human and ecological concerns are coherent and interdependent.

Even with long experience in terms of water use and water management, humans have failed to manage water very well. Throughout the nineteenth century and much of the twentieth century, economic development in many countries was rapid; often at the expense of sound water management practices (Heathcote, 1998). The initial emphasis of watershed management was based on water engineering and forestry, but has since become a multi-disciplinary approach rooted in human ecology and linked to agriculture, rural development, environmental economics and the social sciences. There is a need to re-think the scale of intervention, the upstream-downstream linkages, the temporal and spatial processes, biophysical and socio-economic linkages, and political issues.

A new concept for watersheds is based on recent research and project experience with regard to hydrology and ecology, human ecology and environmental economics (FAO, 2006).

1.2 Watershed Management in Thailand

Thailand is a tropical country, with fertile central plains turned over to paddy fields, and a long narrow land peninsula which stretches southward towards the equator, with the Andaman Sea to the west and the Gulf of Thailand to the east. When one moves north, gently sloping land become uplands and uplands then become highlands. The north of Thailand includes a mountainous area that spreads out through Myanmar, Laos and eventually the south of China; and this is the area this study will focus on (see Figure 1.2).

Figure 1.2: Map of Thailand.
Source: http://www.maps-thailand.com/maps-thailand-files/map-thailand.gif

The north of Thailand covers an area of seventeen million hectares, 33 percent of the Kingdom’s total area of 51 million hectares. There are three million hectares of lowlands, five million hectares of uplands, and the remaining nine million hectares are highlands over 500 meters above sea level. Northern Thailand is situated within the tropical summer-rain region; there are two major forest types (1) deciduous forests: mixed deciduous forest and dry deciduous dipterocarp forest, (2) evergreen forests: seasonal rainforest and mountain evergreen forests. Climatic conditions in the north are specific to this region: the average temperature is relatively low with a wide difference between day-time and night-time temperatures. Compared to other regions of Thailand it is drier in the dry season, but wetter in the wet season. Thus, this causes problems for transportation and creates conditions in which crops are prone to pests and diseases, and the climate is favorable for some semi-temperate crops, while many tropical crops cannot be grown, particularly in the highlands during the cold season (Royal Project Foundation, 2007; Pooma and Barfod, 2001).

One of the most important features of the northern highlands is that they are the source of water for Thailand’s central plains, its agricultural heartland. Highland watersheds are the origin of the four great rivers of the north of Thailand, the Ping, Wang, Yom and Nan, which are the main tributaries of the Chao Praya, the most important river in Thailand. During the past few decades, vast forest areas have been converted to secondary vegetation through the impacts of swidden cultivation and logging. In the mountainous areas, this is particularly critical since the forests serve as watershed protection. However, the forests of the north still remain one of the most important natural resources in Thailand.

The mountainous areas in the north of Thailand are home to dozens of indigenous highland dwellers often referred to as 'hill-tribes'. These hill-tribes have lived in this rugged terrain and have moved around the region without a sense of political or country boundaries, for centuries. The largest hill-tribe group is the Karen, some of whom have been residing in the north of Thailand for several centuries, when most of them arrived in Thailand during the wars with Burma (Myanmar). The most famous of hill-tribes in Thailand are the Hmong people, who originated in the south of China. The Hmong have the longest tradition of growing opium as a cash crop among the hill-tribes. There are also other minority groups residing and sharing the highland territory in the north of Thailand such as the Lahu, Lisu and Akha.

The hill-tribe groups have certain similarities, one of them is the traditional practice of swidden or slash-and-burn agriculture in which the trees are cut, left until they dry and then burned to clear the land and substantially return fertility to the soil in the form of ash. After cultivation and harvesting, the land is left fallow to allow tree to regenerate for a certain period of time (seven years or more), before being re-slashed and burnt. In general, one family may have at least five to seven pieces of land in order to allow this rotation to take place. However, the form of this practice varies among different groups. The Karen has a reputation for sharing a sense of natural resource conservation, whereas the Hmong have little such knowledge. Before the 1960s, the three main crops grown in the highlands were rice, opium and maize. Rice was grown in the rainfed paddy fields along the valleys or in the form of upland rice on sloped swidden fields. Opium was usually grown in conjunction with maize, while other common crops grown were various forms of nuts and tea.

The problem with swidden agriculture starts when the soil is not left to fallow for an adequate period of time, leading to soil fertility degradation and erosion. Due to this form of land and forest management, together with the growing of opium growing, ethnic minorities have been accused by lowlanders of causing forest degradation and of aggravating the risk of soil erosion on steep slopes. One of the national concerns in the late 1960s was deforestation, and again the common, antagonistic view was directed at the hill-tribes. In fact, most of Thailand's deforestation has occurred in regions where hill-tribes do not live, mainly the northeast and the central plains, due to the expansion of agricultural land.

The loss of soil fertility, soil structure degradation and the reduction in forest covered areas is potentially catastrophic. Other characteristics of the highlands that make the ecosystem fragile are the soil structure and slope gradients. The highland soil, particularly on sloping land, has a thin layer of top soil, low organic matter and is relatively uncompressed; thus it is prone to being degraded and vulnerable to erosion. If the structure of the soil and the vegetation cover in watershed areas disintegrate too much, the ground loses its ability to store and channel water adequately (Royal Project Foundation, 2007).

Highland land-forest resource use, changes to the traditional cultivation practices and a population increase among the hill-tribes has contributed to an increase in risk to the fragile highland ecosystem. The political setting and movements set up to deal with natural resource management have been other important issues directly affecting the highland natural resource situation and the well-being of hill-tribes in the north of Thailand. Watershed management in Thailand started in 1953, with reforestation and rehabilitation works carried out on swidden areas or waste land, focused only on the management of shifting areas rather than the application of integrated management action. The Thai Government disseminated information on forest fires and soil and water degradation to the public in order to create common concern with regard to the conservation of natural resources, with the focus on shifting cultivation by the hill-tribes, which it was said denuded the highland areas, especially in the north. Pilot head-watershed protection units were established, responsible for reforestation and watershed relevant research. Due to a lack of both money and knowledge with regard to watershed management and research, the principle applied was just to 're-green' the watershed areas, and the next step; soil and water conservation on sloping land, took place in 1957 to suppress soil erosion in shifting cultivation areas. During the 1960s, the Government legislated protected-area laws such as the National Park, Wildlife Sanctuary and Forest Reserve Acts; this action put more constraints on the life-dependent resources of local and hill-tribes people, and a number of communities were alienated from their places.

In 1964, the Government initiated a watershed management program by setting up the Committee on Watershed Conservation and Development, comprised of eighteen members from government agencies, but this did not function well due to inadequate cooperation among the concerned agencies, and it finally dissolved some years later. During the period 1970 to 1980, a socio-economic development plan in the form of permanent agricultural cultivation was initiated (in the early 1970s) with the aim to replace shifting cultivation practices on mountainous watersheds. In addition, in order to stop deforestation, the Royal Forest Department (RFD) established a pilot integrated watershed and forest land management scheme to find out the best form of land use to be applied for rehabilitating watershed areas in the northern region. It was found that Thailand's bureaucratic structure prevented the achievement of integrated development through a single department; there was no cooperation and no arrangement had been made for the project farmers to have security of land tenure (Pereira, 1989). During this period, the Royal Project was initiated by the King of Thailand, targeted at eradicating opium by crop replacement, improving hill-tribes' livelihoods and highland natural resource conservation.

Efforts at combating resource degradation, deforestation and opium production, particularly in the highland watershed areas, continued. During the 1980s, a number of highland and watershed management projects were initiated and implemented, with budgetary support from and collaboration with international development organizations such as the United Nations Fund for Drug Abuse Control (UNFDAC), US Narcotics Control, the World Bank and countries such as Germany, Norway, Australian and Canada. Other agencies also got involved and took action, such as the Ministry of Defense and five departments from the Ministry of Agriculture and Cooperatives. However, the management of these efforts was under “constitutional-choice”, which provided the legal framework for decision-making on how specific watersheds should be managed and by whom, and this led to complexity in terms of watershed management in northern Thailand (Hoare, 1986; Dearden, 1996).

There were many different policies and plans, even within the same agency. A major emphasis was placed on controlling the activities of the opium-growing hill-tribes, with relatively little attention paid to the subsistence farmers of the highland watersheds. Another important policy framework was provided by the watershed classification system enacted by Cabinet Resolution in 1985. The classification was based on bio-physical characteristics, sought to classify the highland landscapes into five classes that indicated progressively greater restrictions on occupancy and utilization. This resolution set an important blanket policy for agencies working in watershed areas, but was found to be technically and practically flawed in several respects (Hastings and Boonraksa, 1990). During this period, forest land declined, and the FAO signaled a forest conservation alert, plus there was a landslide tragedy in southern Thailand. The Thai government officially banned logging in 1990, but the illegal logging still continued.

The aforementioned development plans and regulations imposed on the highland watersheds affected changes in land use practices and interrupted human-resource interdependencies; some objectives were achieved whereas some other undesirable consequences emerged. Traditional shifting cultivation practices were phased out - moving toward permanent agriculture, and the farmland holding area decreased. Crop replacement strategies worked well at the beginning, but due to transportation improvements in highland areas, allowing the release of crop products to down-town markets, crop product prices declined, and this forced farmers in the highland to expand their farmland and/or intensify crop cultivation. Road construction projects and the conversion of forest to farmland accelerated the degradation of land and forest resources in watershed areas. Soils became more prone to erosion due to the reduced forest cover and a greater demand for irrigation. This even led to conflict among farmers over shared water resources and conflicts of interest among highland people and the agencies responsible for watershed resource management.

1.3 Participatory Modeling and Simulation for Integrated Watershed Management

It has been widely acknowledged that the key issues that have contributed to the failure or success of natural resource management are dialogues among multiple stakeholders, the existence of multi-layered institutions, the presence of diverse tools and methods to facilitate scenario experiments, plus knowledge improvement and a co-management process (Borrini-Feyerabend et al., 2000; Dietz et al., 2003). Recently, there have been calls for more inclusive and deliberative approaches in terms of natural resource management. A broad range and different degree of stakeholder involvement has been explored (Hare et al., 2003; Soncini-Sessa et al., 2003; Caminiti, 2004; Lanini et al., 2004), and different modeling tools have also been used to facilitate such deliberative approaches.

Multi-agent system modeling (MAS) has been developed to explore and understand the complexity of systems through agents' behavior and interactions (Gilbert and Troitzsch, 2005). It has been increasingly used to deal with ecological and socio-economic issues arising from the management of scarce resources by multiple users (Janssen, 2002; Feuillette et al, 2003). Integrating MAS with other biophysical or economic models and spatial database tools can enhance the adaptive learning capability (Holling, 1978) of all stakeholders regarding their roles, and has an effect on ecological system dynamics. This has tremendous potential for assisting decision-makers in understanding and managing landscapes (Le Page et al., 2001; Gimblett, 2002; Parker et al., 2003). Various integrative empirical methods and tools have been used for constructing the model and for the development of different research questions and objectives (Janssen and Ostrom, 2006; Berger and Schreinemachers, 2006; Robinson et al., 2007; Brown et al., 2008).

The role-playing game (RPG) is a mediating tool used to understand interactions among individuals' behavior, and helps to enhance participatory rural appraisal, empower stakeholders and facilitate resource management (Forester, 1999). The so-called "companion modelling" or ComMod approach, integrates RPG into the participatory MAS modelling process in order to improve the understanding of complex phenomena and to develop, modify and validate MAS models (Bousquet et al., 1999; Barreteau, 2003a). The ComMod approach aims to empower stakeholders through the acquisition of a clear understanding and a long-term vision of their system dynamics. RPG can facilitate collective learning, negotiation and collective decision-making among stakeholders, allowing participants to cooperate and manage their natural resources collectively. Over the last ten years, the application of ComMod has been directed towards various human-environment contexts and for alternative uses in different places (D'Aquino et al., 2003; Barreteau, 2003b). Dynamic modelling and MAS approaches for soil and water resource management have been applied in watershed areas of northern Thailand (Becu et al., 2003; Barnaud et al., 2007; Becu et al., 2008), as well as for watershed conflict resolution in Bhutan (Gurung et al., 2006). The degree of stakeholder participation, institutional involvement and the methodologies used, have varied depending upon the research objectives and the heterogeneities of the local contexts. For instance, in a highlands of Vietnam, a combination of bottom-up and top-down approaches was used to extend shared common representation among multi-level stakeholders, when the scale of interest increased and other stakeholders had to be involved (Boissau and Castella, 2003; Castella et al., 2007).

The ComMod approach promotes a flexible use of different tools, such as RPG, computer simulations, field surveys, focus group discussions and collective workshops. These tools can be linked together in different ways depending on the context, the social process at stake and the collective objective that has emerge from the interactions (Trébuil, 2008). For example, Barnaud et al. (2007) first developed a computer simulation model that integrated scientific knowledge about biophysical processes and agricultural practices, and was then simplified into an RPG aimed at sharing scientific perceptions. The stakeholders validated part of it and asked the scientists to modify the RPG model and used it for other topics. The RPG has thus become a collective tool, leaving the scientific model aside. Gurung et al. (2006) designed a simple RPG to facilitate the negotiations among stakeholders, but did not integrate scientific knowledge into the model. Becu et al. (2003) developed a specific method (playing stories) to elicit individual mental models of farmers with regard to irrigation, and then integrated these models into a computer simulation model. They later conducted a participatory simulation to support decision-making among the stakeholders, as well as to assess the potential and limits of stakeholder involvement (Becu et al., 2008).

1.4 Problem Statement

The highland watershed areas in northern Thailand have been generally perceived as the fragile, vulnerable and susceptible national asset, and so have been brought under the protection and management of the Thai Central Government. Highland peoples and their agricultural activities are perceived by the public as having contributed to forest, land and water resources degradation; meanwhile, the 1997 Thai constitution explicitly emphasized the involvement of local people in decision-making processes related to environmental management. Responsibilities were divided among different branches of Thai government agencies and local authorities. One important local organization that resulted from this policy was the Tambon (sub-district) Administration Organization (TAO), which is locally and directly responsible for social development and environmental and natural resource conservation. Over the past decade, this has resulted in a strong horizontal interplay between different systems of rules and implementing organizations (Lebel, 2005). However, local stakeholder participation has not often gone beyond the informative and consultative stage *"The episodic and ceremonial character of many participatory exercises, such as public hearings, under the state-driven approaches fails to enhance two-way communication processes and to build trust among stakeholders with varying an often dissenting – perspectives. Rather than incorporating local initiatives into a broader decision-making effort at the river basin levels, these state-driven institutions have created a parallel universe, in which 'participation' is used as a label to gain legitimacy for preconceived objectives and implementation plans"*(Neef, 2008). While the Government holds all the rights over most natural resource management activities, especially in watershed areas, it is difficult for local communities to participate in policy decision-making processes. Forest devolution, under the environmental decentralization policy which emerged after 1997, has not been very effective and has not provided local communities with greater decision-making power.

Thus, in the context of the northern watersheds of Thailand, a number of complexities and difficulties in resource management have arisen from the following conditions:

- Northern watershed is a national target to be conserved as “head-water areas” and “natural resource richness” areas, thus any activities there are especially “watched” by the public and are of concern.
- There are a number of agencies involved in making decisions on and managing watershed resources, with specific objectives, scales of interest and pathways to achieve given tasks. Some of their individual actions may not link together very well.
- There are different rules and regulations applied that constrain the way of life of people who reside in the areas. The data and information used for formulating some of these regulations has not been suitably accurate and has mismatched with the truth on the ground, thus some regulations have not been effectively implemented.
- Agricultural activities in highland areas have been accelerated and intensified “beyond self-sufficiency needs”, due to economic and market driven processes and population pressure. These activities are resource dependent, thus they make watershed resources and ecosystems more vulnerable.
- The decentralization policy gives the right to local people and organizations to manage their own natural resources, but there is no effective platform to facilitate and empower local communities to gain better and real participation in the decision-making activities related to watershed resource management.

1.5 Research Questions

Although all scholars who have been involved in resource management arena agree upon the above remarks, everyone kept in mind what should be considered and how to tackle these issues. However, there have been several approaches and tools adopted and applied; each might achieved some of the mentions while left some others for further explorations and efforts. In this thesis work, it will focus in particular on the issues outlined in the problem statement and the research objectives, by exploring implementation of the ComMod approach and tools.

The keys issues focused on the northern watershed area of northern Thailand are:

1. There is no effective platform and no procedures to enhance the understanding of local people with regard to the inter-dependencies among individuals and the consequences on watershed resources that may arise from individual actions and the interaction among them.
2. It is hard to broaden and share common representation and knowledge with regard to watershed resource management at the individual level and link this to the higher institutional levels where other stakeholders are involved.
3. Conditions and problems are very dynamic.

From the existing approaches, within the context of a multiple-level of stakeholder organizations (individual and institutional) and the multi-layered policies and organizations involved, the research questions have been formulated as follows:

1. How can the companion modeling approach and mediated tools be applied to promote the mutual and adaptive learning of stakeholders, so as to understand the roles and consequences that may arise from individual actions and the interactions among them?
2. How can the participatory approach and mediated tools be applied to promote collective watershed resource management?

1.6 Study Site, Materials and Methods

This research aims to present the specific Commod process and other complementary tools (including literature reviews, preliminary social-ecosystem analysis, Geographic Information Systems (GIS), field surveys and co-investigations with multi-level stakeholder engagement) used in the watersheds of northern Thailand. It illustrates the uses of different RPGs to promote a mutual understanding of the complex natural resource management problems existing in a watershed area. This is then combined with the findings from other RPGs and participatory activities that have engaged stakeholders in multi-layered institutions in order to build a computerized MAS model, one that represents the heterogeneity of agents, and their communications and interactions with the environment. The objective of the model is to explore the scenarios suggested by stakeholders, those that facilitate understanding and stimulate a collective dialogue regarding feasible resource management schemes.

This study targets Maehae communities as the study site. There are two ethnic groups scattered across fourteen communities (whereas only four official villages are designated) and two sub-watersheds. The agricultural practices in Maehae are mainly rice and cash crops (vegetables and fruit trees) which, in addition to household consumption, are highly dependent on market driven factors, and intensive land and water resource use. The Maehae social-ecosystem context holds the main features of a ‘complex’ watershed resource management regime in northern Thailand, one that challenges implementation of the proposed Commod approach and its integrative and evolving processes, which requires high levels of participation from multiple stakeholders.

A multi-disciplinary research group based at the Multiple Cropping Center, Chiang Mai University in Thailand, conducted research comparing land use changes between two highland areas under the RPF's responsibility; showing that the forest area in Maehae has been well maintained (Ekasingh et al., 2001). Further investigation was conducted to conceptualize the system and its functions. The secondary data was collected from literature reviews, particularly reports from research works previously conducted in the study area on land use and land use change, plus from socio-economic analysis. This data gathering also included spatial data (GIS and aerial photos) to detail the aerial distribution of different land utilization types. The objective was to analyze land and forest resource use and management and its dynamics.

In this case study, field surveys were conducted to collect primary data by interviewing local key informants, administrators and other agencies who have a role in agricultural development and watershed resource protection and conservation, such as the head of the Maehae RPF development unit and the local forestry officer. The purpose was to analyze the institutional setups and farming systems in relation to land and forest resource use and management. This preliminary system analysis result was used for conceptualization of the Maehae social-ecosystem, something that helps elaborate the major resource components, stakeholders and inter-relationship among these two key elements. This initial finding was used to guide further knowledge inquiries and investigation through an adaptive and evolving Commod processes.

1.7 Organization of the Manuscript

This manuscript presents six chapters, providing details on the sequence of the different participatory investigation steps and their findings.

Chapter 2 provides further detail and background on natural resource management and related policies in Thailand, particularly how these link to changes and complexities in the human-socio-ecosystem for watershed management in the northern region. It then presents a review of the approaches and tools employed in natural resource management, where human decision-making and interventions are keys to the dynamics and to the changes involved. It ends with a review of the methods used by several scholars in the northern Thai watersheds.

The results of the system analysis of the study area, namely Maehae, are presented in Chapter 3. This explains and clarifies how watershed management is this area has become so complex, with multiple-stakeholders and multiple layers of relevant policies.

Chapter 4 illustrates the implementation of the companion modeling tools, such as land-forest role-playing games, water management role playing games and surveys. As the tension among water users in upstream and downstream areas is perceived to be resolvable through collective action at the community and institution level, the performance of a co-investigation with multi-level stakeholder engagement will be reviewed. Numerous forms of information (GIS maps and aerial photos) and analysis tools were applied to facilitate a series of collective activities. Along with this, further knowledge and understanding on behavior, the decision-making process, interaction among multiple stakeholders and local institutions, as well as the plausible solutions commonly suggested through a number of group discussions, were observed and collected.

Chapter 5 explains the linkages between the previous findings and the multi-agent based model (MABM) built under the Cormas (Common-pool Resource Multi-Agents System) platform. The chapter explains how the results from the RPGs and findings from the community and institution engagement were integrated into the Maehae model, a model that represents the keys features, interactions and dynamics of the system. UML diagrams are used as a means to transform a common understanding of the Maehae system and its dynamics into the design and development of the Maehae model. The second part of Chapter 5 explores alternative management scenarios derived from the suggestions of the stakeholders. The simulation results will then be analyzed, taking into account the emergent properties of watershed resource availability, agricultural productivity and economic venue, and the equitability of income distribution.

At the end, chapter 6 wraps-up and highlights the research process and the findings; criticizing how the experiences and findings from this study will contribute to participatory modelling and the ComMod approach in terms of sustainable watershed management. It will also stress the importance of having local policy networks in place.

CHAPTER 2: CONTEXT ON WATERSHED MANAGEMENT IN THAILAND AND STATE OF THE ART ON MODELING FOR LAND AND WATER MANAGEMENT

2.1 Watershed Management in Northern Thailand

The human-agroecosystem of upper northern Thailand is characterized by its geographical structure, mountainous tropical forest ecosystem, and the presence of various ethnic groups scattered across the highland areas, those that practice agriculture for staple food and cash crop production. It covers an area of about 2,200 km^2 of mountainous land, and the elevations range from 1,000 to 2,000 meters above mean sea level (AMSL). Most of the area is government forest land. There is a population of almost a million highlanders in the area; mostly the 'hill tribe' people and members of minority groups. The majority are relatively poor, poorly educated and practice shifting cultivation; their cultures and languages are different.

The majority of forest cover in the area is made up of deciduous and evergreen forests. In more recent years, vast forest areas have been converted to secondary vegetation through the impacts of logging and swidden cultivation carried out by the hill tribe people. These farmers farm on sloping land without using any soil or water conservation measures. After using their farmland for four to five years and after the nutrients in the soil have declined, the farmers move to clear other pieces of fertile forest land. This improper use of land has led to problems with the soil and water in the area. In the montane areas this is particularly critical, since the forests serve as watershed protection; however, the forests of the north of Thailand still remain one of the most important natural resources in the country.

Major transitions in terms of the human and highland socio-ecosystem have evolved in line with the focus and changes in the Thai political system since the mid 1800s. This section elaborates on how these changes and transitions have occurred and the consequences for the complex area of watershed management in the north of Thailand.

2.1.1 People and Administrative Set-up

Thailand is administratively divided into four regions: Northern, Northeastern, Central and Southern. The Northern region is made up of 17 provinces. In the north, rural households normally cluster together. A village (*mooban*) – the smallest administrative unit and headed by the village headman, is comprised of between one or two clusters of, or even more highland villages. Several villages make up a sub-district (*tambon*), headed by a *Kamnan,* who reports to the *Nai Amphur,* or district officer, who in turn reports to the Provincial Governor. This direct administrative line used to be under the Central Government, through the Ministry of Interior (Rerkasem and Rerkasem, 1994).

According to the development and welfare policy for highland peoples of the Department of Public Welfare (Cabinet resolution on 6th July 1976), *chao khao* is the term used to define the members of ethnic groups with different races, traditions, customs, culture and beliefs from the majority of the ethnic 'Thai' peoples. In the official statistics of Thailand, ten different ethnic minorities are categorized as "hill tribes" or "ethnic groups", referring to their geographical location in the northern and western mountains of Thailand. Most of the groups live in a scattered fashion and are not confined to a specific territory (Gravers, 2001). The majority of these groups moved to live in northern Thailand during the 1800s or early 1900s, although some have been there much longer. During the 1960s, as the infrastructure development and cash crop boom along the upland frontier materialized, the hill tribe population increased significantly (Isager, 2001).

In 1988, the total number in this category was 551,144 or about one percent of the total population of Thailand at that time. In 1995, the Tribal Research Centre registered 3,595 villages with a total population of 694,720 persons belonging to ethnic groups. The actual figure could well have been a little higher due to recent immigration, or a lack of registration and movement of the people. The data on highland populations investigated by the Hill tribe Welfare Division of Public Welfare, shows that there are altogether 774,316 *chao khao*, and 139,797 households across 3,746 villages (Rerkasem and Rerkasem, 1994). A total of 991,122 persons live in uphill communities across twenty provinces in the north and the northwest of Thailand (Table 2.1), according to the Ministry of the Labor and Social Welfare (Gravers, 2001).

Table 2.1 Ethnic Groups and Populations in 1998.

Ethnic Group	No. of Villages	No. of Households	Population
Karen (or Kariang)	2,130	70,892	353,574
Hmong (or Meo)	266	15,704	126,300
Lahu (or Musur)	446	15,388	85,485
Aka (or Ikaw)	276	9,740	56,616
Yao (or Mien)	195	9,501	48,357
H'Tin	151	7,058	38,823
Lisu (or Lisaw)	161	5,652	33,365
Lua (or Lawa)	71	3,322	17,637
Khamu	47	2,515	13,674
Mabree	3	24	125

Source: Department of Social Welfare, Ministry of the Labor and Social Welfare, Bangkok.

Five out of nine ethnic groups are traditionally opium growers, and in addition, some Karen villages have become dependent on opium in terms of acting as wage labor for richer opium growing villages. The suitable land for opium growing is located at high altitudes ranging from 1,000 to 1,500 MASL. Prior to 1980 a highland population of some 200,000 across 1,000 villages, was dependent on opium as the major proportion of its income. Almost all the production area was in three provinces: Chiang Rai, Mae Hong Son and Chiang Mai. The opium growing area in the early 1980s was between 30,000 to 50,000 rai (1 rai = 0.16 ha). In 1958, the Thai Government enacted legislation prohibiting the use of opium; followed by the Narcotic Control Acts of 1976 and 1977, which established greater control over all phases of the production, trade and consumption of opium and its derivatives. This law was strictly enforced after 1985, and a decline of 200,000 rai in the opium growing area was reported (Rerkasem and Rerkasem, 1994).

Before 1945, the Thai Government had a monopoly on opium production, which had been enormously profitable to it and the individuals working there. In 1958, the International Opium Protocol was promulgated, and under pressure from the international community, the Government in Thailand proclaimed its Opium Act, forbidding the production, consumption and sale of opium. Enormous effort from the Thai Government and international narcotics control organizations was exerted to eradicate the opium, and cash crop replacement was one of the strategies used to do this. However, the opium growing still continued for decades after that, because the opium eradication strategies were simplistic and unworkable. Crop replacement did not result in improved economic conditions; on the contrary, economic life was considered by villagers to be more insecure than it had been in the days of the opium economy. Marketing, particularly finding ways to get cash crops to markets, was and still is a major obstacle to all of these projects (Gillogly, 2004).

2.1.2 Forest, Watershed and Policies

2.1.2.1 Forest and Relevant Policies

Forestry has been an important factor in Thailand’s development and the building of the national economy. Thai state regulation of land and forest use has evolved over centuries. Forest legislation began in 1896 as an initiative of the Royal Forest Department (RFD). This was a step in line with the process of centralization and modernization, related to the new system of administration. From then on, all rights to the forests were officially transferred from the local governor to the Central Government in Bangkok, and timber concessions throughout the country were to be granted by the RFD alone; teak extraction without the payment of royalties was prohibited. This obviously marked a disruption in the traditional ties between the rulers in the lowlands and the highlanders, who had been incorporated into the lowland governance structure as taxpayers, having the right to live in such highland areas (Isager, 2001).

The Forest Care Act of 1913 brought selected species other than teak under Central Government control; silviculture, forest products research and forest schools were implemented. Legal reforms began in 1936 and were continuously implemented through to 1953. The Forest Act declared certain areas to be state land without regard for existing villages (Gillogly, 2004). By 1953, about 60percent of total land area of the Kingdom remained as forest, with regional levels ranging from 50percent in the northeast and the south, to about 60percent in the central region and 70percent in the north. Harvest concessions covered about 40percent of the land in the north, and very little elsewhere (Pragtong and Thomas, 1990).

In 1941, The Land Code Act of 1954 further asserted state control over the uplands. For mountain villages, only paddy fields were potentially recognized as being privately owned, but the owners had to request recognition of this. In all of these cases, mountain peoples lacked knowledge of the Thai legal system, and so never requested recognition (Ganjanapan, 1998). The process of land alienation proceeded further with the establishment of national parks and wildlife sanctuaries in 1962, followed by watershed conservation units and the National Forest Reserve Act of 1964. This Act gave the Government control over resources that it had never controlled before. In 1968, the National Reserve Forests Act detailed the punishments imposed for destruction of the forest. As forest cover dropped under 50percent, the forest target was revised to 40percent of the land area. The cycle of crime and punishment was devastating to small farmers who depended on swiddening for their livelihoods, but had no effect on large-scale logging companies (Gillogly, 2004).

After 1958, a coup d'etat marked the beginning of an era of economic growth in Thailand, with initiation of the National Economic Development Plan for 1961 to 1966. The development of infrastructure in Thailand, combined with the rising demand for agricultural products in Europe and the USA after the 1950s, provided the conditions for the expansion of agricultural production in Thailand, and the expansion was at a rate of about 70,000 to 80,000 farm holdings per year. Transformation of the landscape began to accelerate during this period, and by 1967, forest cover had dropped to 48percent of the Kingdom's land area, while farm holdings had grown to 26percent and population density had risen to over 62 persons per square kilometer. In 1974, the Government declared an amnesty for those residing in reserve forest lands, and growing concerns regarding environmental deterioration resulted in the National Environmental Quality Act and establishment of the National Environment Board in 1975. The planning approach to resolving land-use conflicts was reflected in the 1975 Town and Country Planning Act (Pragtong and Thomas, 1990).

During the late 1970s and early 1980s it became clear that the expansion of the "upland frontier" had led to dramatic deforestation of the country. Whereas 53percent of the country had been covered by forest in 1953, less than 30percent was still forested by the 1980s. In northern Thailand, 68percent of the land was forested in 1961, but in 1976, the figure was 60percent, and by 1978, only two years later, it had dropped to 56percent. By 1985, less than 50percent of northern Thailand was covered by forest. Since the official logging ban was introduced in 1989, the forest cover has stabilized at about 43percent for the north and less than 25percent for Thailand as a whole (Royal Forest Department, 1998). Part of the original deforestation was directly related to the perceived communist insurgency during the 1970s. During this period the Government cleared large forest areas and encouraged lowland farmers to settle there. It has been estimated that between 1973 and 1982, a total of 6.5 million hectares of forest in Thailand were destroyed for this purpose (Isager, 2001)

During the 1980s, forest conservation and the protection of wildlife became issues of urgent public and state concern. The national logging ban in 1989 was one of the Government’s responses to popular unrest and international pressure over rain forest conservation. State conservation strategies impacted more on the ethnic minority groups than on the Thai people in general; many forest-dwelling groups were forced to move from their villages (Isager, 2001). Despite this, proportionately less forest was destroyed in the north than in other parts of the country. By 1990, nearly 70percent of Thailand’s remaining forests were in the north. The north is also the most significant watershed for the central plains, and as such is a special target for forest protection (Gillogly, 2004).

2.1.2.2 Watersheds

During the fifteen year period from 1967 to 1982, existing forests in the upper north of Thailand decreased in area by about 49.2percent. This diminution of the natural forest cover led to a degradation of the basin, as manifested by the problems of soil erosion and the subsequent deposition of sediment. In addition to land and forest resources, water is also a contested resource. The main water management strategy in Thailand, as addressed in general, has been to assure a sufficient quantity, and quality of water, and to ensure equitability among users. The highland northern areas of Thailand were designated as very important areas of forest protection for the provision of water services, for eradicating water shortages during the dry season and floods during the wet season, but these aims and problems led the Government to promulgate the 1985 Cabinet Resolution named ‘watershed classification’. This resolution classified watershed area in Thailand into five zones and employed five parameters, these being: slope, elevation, landform, soil and geology, in order to derive watershed class equations for a particular region with the additional conditions of forest or non-forest use existing for the first two classes. The defined watersheds classes allow for and/or constrain resource utilization in a given area (Lakanavichian, 2001; Tangtham, 1996).

Watershed classification is an extension of land use planning for forest areas, something which will properly allocate land across various uses. For Thailand, the specific objectives of this project are to distinguish between areas to be permanently protected as forest watershed cover, and those areas to be used for commercial forests, plus areas open for the utilization of all resources, or for conversion to agronomic uses; and recommends appropriate land-use practices. The five watershed classes and their characteristics are shown in Table 2.2.

Table 2.2 Watershed Class (WSC) Characteristics.

WSC	Characteristics
1	Protected or conservation forest and headwater source. This class is divided into two sub-classes
1A	Protected forest areas including the headwaters of rivers. These areas are usually at high elevations, have very steep slopes, and should remain in permanent forest cover.
1B	Areas which have similar physical and environmental features to 1A; however a proportion of these areas has already been cleared for agricultural use and occupation. These areas may be fallow or cultivated; they require special soil conservation protection measures. Where possible, they should be replanted to forest or maintained as permanent agro-forestry.
2	Commercial forest designed for protection, and/or commercial forests where mining and logging are allowed, within legal boundaries. This is usually at high elevations with steep to very steep slopes. Landforms usually result in less erosion than for WSC 1A and 1B. These areas may be used for grazing or crop production if accompanied by appropriate soil protection measures.
3	Fruit-tree plantations. These areas cover uplands with steep slopes and less erosive landforms. Areas may be used for commercial forests, grazing, fruit trees or certain agricultural crops, with a need for soil conservation measures.
4	Upland farming. This class describes those areas of gentle sloping land suitable for row crops, fruit trees and grazing, with a moderate need for soil conservation measures.
5	Lowland farming. These areas have gentle slopes or are flat, suitable for paddy fields or other agricultural utilization, with few restrictions.

In Thailand, there are 25 main watersheds, and 254 sub-watersheds areas, and four out of the nine primary watersheds in the north (Ping, Wang, Yom and Nan) are part of the Choa-Praya river basin, the most important river basin of the country. The tributaries and the main river of this basin feed the central plain - the main rice producing area, and also provide water for domestic consumption in several provinces along the river, including in Bangkok (Figure 2.1).

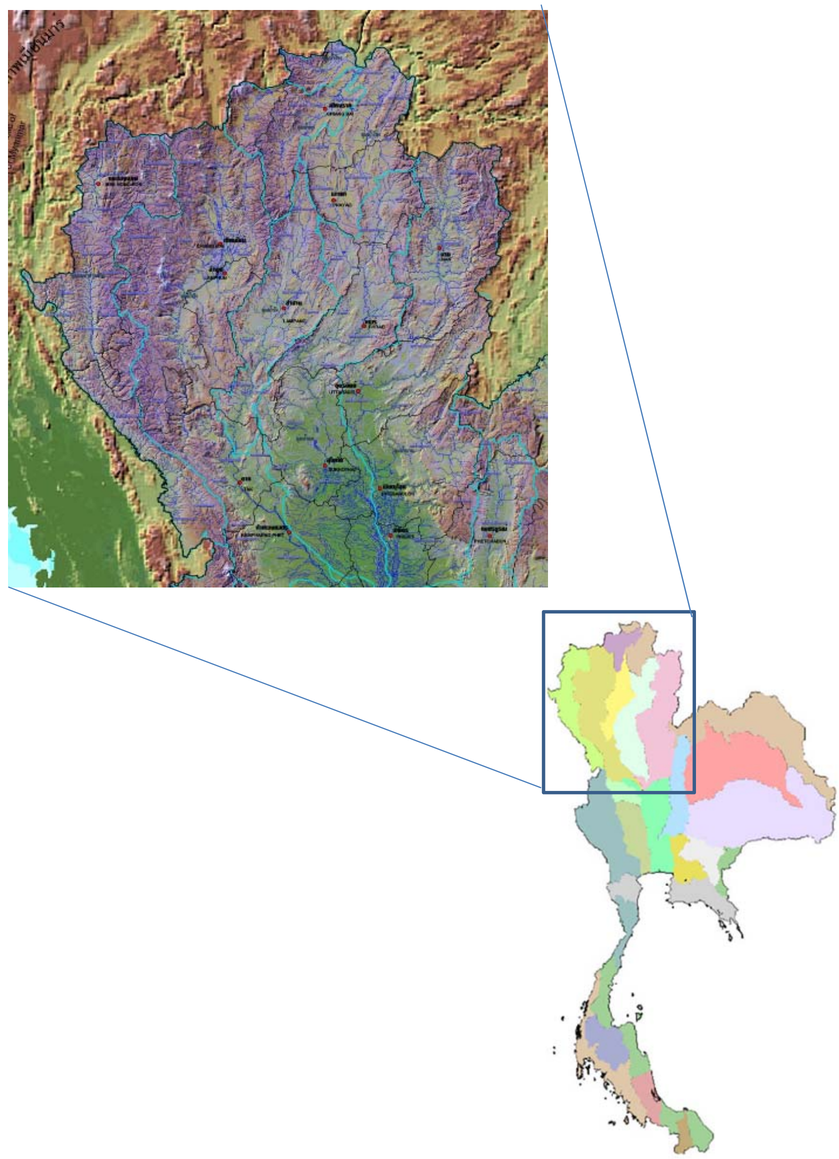


Figure 2.1: Thailand's 25 Main Watersheds and Sub-watersheds in the North

At the national level, about eighteen percent of the country area is classified as WSC1. The four primary watershed areas cover 102,635 km^2 or 74.17 percent of the northern region; the areas that fall into WSC1A make up about 25.14 percent (Table 2.3).

Table 2.3: Distribution of WSC and Resource Status of the Four Primary Basins in Northern Thailand

Basin	Area (km^2)	Aerial distribution; % of WSC				% Forest Cover
		1A	1B	2	3-5	
Mae Nam Ping	33,898	36	2	14	48	49
Mae Nam Wang	10,791	23	1	14	62	61
Mae Nam Yom	23,616	18	1	13	68	33
Mae Nam Nan	34,330	20	1	18	61	43

Source: Modified from Tangtham (1996).

Since implementing the cabinet resolution on watershed classification twenty years ago, several problems and constraints have arisen regarding technical methodology and watershed class boundary delineation, as well as due to the impractical nature of application within the Thai political and socio-cultural reality. One problem is the gap between the definition of a watershed and bringing it into practice. The defined A1 watershed area seems to be defined across over the old cultivated areas. The WSC parameters, based on 1x1 km^2, have been questioned and cause errors especially for those areas located in valleys, sloping areas and floodplains along the valleys. An effort to revise the classification was made in 2005, using up-to-date GIS technology; however this I still going through the process of cabinet approval (Pattanakiet and Tangtham, 2006).

However, the watershed classification and its sequential implementation have taken place, regardless of any historical interaction with human beings. The definition of the watersheds has been disputed since the official classifications were made. For example, the classification takes only ecological factors into account; socio-economic factors such as water availability, infrastructure and the location of villages were not analyzed; it was a purely manual analysis and used a very broad scale of basic data and outdated material (TM50, 1967) such as the smallest grid size was one km^2 and class applications were based on slope and elevation ranges analyzed through visual interpretation of the contour line TM50. Laungaramsri (2000) argues that it is not merely an objective definition, but is socially and politically embedded in an unequal relationship. For the RFD definition, the watershed designates a geographical space; *"a line of high land where streams on one side flow into one river, on the other side flow into a different river"*. However, in the modern management of water resources, such classifications are just as indispensable as those used by the highlanders during their life and work.

2.1.2.3 Decentralization and Resource Management

In Thailand, watershed management has been an arena of conflict between the RFD and upland hill/highland people for more than three decades (Sato, 2003). It is an interesting coincidence that the promulgation of the new constitution in September 1997, known as the 'democratic constitution', came right after a major economic crisis. The state is obliged to encourage civil society participation in the conservation and management of natural resources. Decentralization of decision making in regard to natural resources has been enabled. Popular participation in resource use and management, once considered merely an instrument for rural development, was now viewed as a central force to help overcome the economic crisis. However, the official recognition of the people's right to participate does not necessarily correspond with the actual practice in terms of resource control. In fact, the new constitution may have increased the incidents of land conflict, now that people stand a better chance of gaining at least something; the number of reported disputes over land control has increased.

In light of these considerations, it is not enough to seek sustainable forest use with an exclusive focus on the village-level mechanics of collective action. All forests are by definition legally under the ownership of the State. A much-debated political solution to resource problems, especially since the 1990s, has been the transfer of resource management responsibilities from the State to the hands of local communities. In Thailand, the enactment of the Community Forestry Bill is considered one such solution to the problems of deforestation and social injustice. The completion of the first draft by the RFD was in 1992, and then in October 2001, the lower house passed the Bill, including the controversial. The 8th national Plan (1996-2001) stated the important of the development and conservation of surface and ground water, and this vision was adopted by the government; a New Thailand Water Policy has been adopted by the Cabinet in 2000. One of the main points in this policy statement is equitable allocation of water for all water use sectors while fulfilling basic requirements of the agricultural and domestic sectors, to be achieved through the establishment of river basin specific priorities, which in turn will be clear allocation criteria. Beneficiaries should share costs according to service and capacity. In 2002, the Government established a new Ministry of Natural Resources and Environments (MONRE); the powers and duties given to MONRE are concerned with the preservation, conservation, rehabilitation of natural resources and environment, management and sustainable use of resources and implementation of other government services. However, these supportive policies to the decentralization effort for resources governance in Thailand have been stumbled by the coup d’état in 2006.

2.1.3 Natural Resources and their Management in the Highlands of Northern Thailand

During the 1990s, public environmental awareness grew rapidly, bringing conflict between lowland and urban communities associated with the natural resource situation in the highland and watershed areas. Instances of conflict about water use among upland and lowland communities occurred in Chiang Mai in the late 1990s; lowland communities blamed the scarcity and chemical contamination of downstream water on agricultural activities in the uplands, and so demonstrated and obstructed transportation between the uplands and the city.

This rapid changes and the impacts on social, economic and natural resources have been complex and unpredictable, and this has driven development and research efforts from many sectors, and several policies and projects with various development strategies have been proposed and implemented to tackle the problem, especially in highland watershed areas. Since 1970, a number of highland development projects have been implemented. Many of these have received funding assistance from foreign governments and from international organizations. Obviously, a huge portion of their budgets have been allocated to project administration, and have rarely reached the villages (Enters, 1995; Rerkasem and Rerkasem, 1994). Some of these projects have involved local people in the process, but have still focused on small target areas and have rarely incorporated all local government agencies. Eventually, the influence on national policy formulation for natural resource management has been small, and the processes of policy-making and implementation continue to rely mostly on a top-down approach.

Since these times development agencies have experienced a failure to manage natural resources, because of their complexity and dynamic context, so they have turned emphasize a participatory development approach, one that has opened the door to local involvement in resource management decisions (Missingham, 2001). This approach was officially endorsed in both the Eighth and Ninth National Economic and Social Development Plan (1992 to 1996 and 1997 to 2001 respectively). In 1997, Thailand adopted a new national constitution which strengthened the role of local government institutions. Later on, this resulted in a range of new policies aimed at empowering stakeholders and institutions in terms of participating in the management of their own local resources in a sustainable way. However, neither suitable practical tools nor a clear mandate to achieve the goal was made available at this time; thus, roles and actions taking place in watershed areas appeared to result in unpredictable changes to the land-use practices, productivity, and food security situation in the highland communities.

2.2 Integrated Watershed Management

2.2.1 Issues, Approaches and Challenges

The aforementioned aspects attached to the complexity of watershed management are interdependent; the spatial ‘natural’ boundary is no longer appropriate to define management scope, but human dimensions (social, economic and policy) have become the key points of concern, with multiple stakeholders and different institutional settings. The integrated watershed management approach has become a highlight for all the sectors involved and thus plays a role in this arena. The general practices and issues experienced by research and development efforts with regard to watershed management across numerous watershed areas have, one after another shared lessons and raised challenges to be further explored by us; to catch up with the rapid changes in human-ecology relationships and to steer actions toward sustainable watershed management.

Heathcote (1998) remarks that integrated management is needed in order to focus and incorporate all parties to participate with processes, apply decision-support system tools to explore a range of impacts resulting from such decision making or implementation, and to ensure that all process and relevant information are open for public participation. He adds that both planning and management processes must be responsive and adaptive to changing conditions. FAO (2002 examines the relationship between land use and water resources, identifies mechanisms and instruments for sharing the benefits and costs resulting from the impacts of land on water resources flowing between upstream and downstream stakeholders; and suggests further aspects to be addressed with regard to integrated watershed management. These suggestions are: to carry out a spatial and temporal scale impacts assessment; the use of integrated participatory tools to work with stakeholders in terms of negotiation and resolution, verifying stakeholders’ understanding of the decision-making processes, identifying the costs and benefits resulting from such proposed management schemes, and that a benefit sharing mechanism should exist.

Institutional analysis, social learning, stakeholder participation and collaborative management have often been mentioned as key aspects to be considered when implementing such a watershed management. Watershed management initiatives "face numerous obstacles, more social than hydrologic" (Kraft et al., 1999), and the key to their success may be "the degree of political commitment to the objectives by those who have authority to act". Although there has been criticism that collaborative management efforts are impossible, impractical, or can emerge only on small scale, and perhaps may even be illegal (Tarlock, 2000), or that "science can offer no help in this problem" (Pereira, 1989); it has been crucially remarked upon during the past two decades that watershed management should bring all "stakeholders" together, and should be implemented through some form of watershed authority or through cooperative coordination among existing agencies. The key questions are where the boundaries should be drawn, how participation should be structured, and how and to whom decision makers within a watershed area are accountable. It is important to consider the "watershed as a geographic and socioeconomic unit", and how the boundary mismatch between the two contributes to political problems (Blomquist and Schlager, 2005).

Watershed management, as part of natural resource management, is complex and dynamic and should be approached from a broad perspective, taking all potential trade-offs and different scales in terms of space and time into account. Participatory and adaptive management is needed to cope with the increasing uncertainties arising from fast-changing socio-economic conditions, as well as global and climate changes. This can be achieved through a social learning processes together with bringing discipline into new fields to tackle the research questions required to understand the complex dynamics of human-environmental systems (Pahl-Wostl et al., 2007). German et al. (2007) explore how participation and integration may be conducted in practice. He addresses interesting concerns on watershed management which are: management of the trade-offs for diverse stakeholders/groups, ways to optimize the returns for diverse social groups and system components, while minimizing the negative spin-offs. Thus, they propose the question to all watershed managers: "watershed management for whom?", as a clarification of the intended beneficiaries. The other concerns made for suggestions are problem identification with all groups, unequal in power and expression.

2.2.2 Tools and Methods for Integrated Watershed Management

The issues, approaches and challenges with regard to achieving effective watershed management, as mentioned earlier, can be summarized as follows.

- A "watershed" unit needs to be defined using natural and non-biophysical parameters (administrative and cultural units) and its trans-boundary resources.
- Interdisciplinary knowledge integration is compulsory.

- All parties should be adequately incorporated into all the processes (for example, problem identification, decision-making, exploring the impacts and costs and benefits of alternative decisions made).
- Integrated participatory tools are needed to explore such proposed management schemes with regard to cost-benefits or the trade-offs resulting from implementation, and their distribution to each of the individuals or groups of stakeholders.
- Integrated watershed planning and management must be responsive and adaptive to changing conditions.
- Social learning is crucial for coping with uncertainty, and to enhance the capability required for adaptive management.
- A watershed management plan must be revisited and reviewed periodically to determine whether it is still acceptable or could be improved.

Each of these aspects may be accomplished through utilizing scientific knowledge and tools; however when implementation takes place, all the processes need to connect to each other, as one step will affect or determine further procedures. Therefore, integrative tools are needed to take into account and to achieve those essential elements mentioned above, as a whole process. NRM involves the complexities arising from combining interactions and inter-relations between bio-physical dynamics and human actions. Furthermore, these two major NRM relevant components are highly interdependent: a change occurring on one side will alter or trigger a change in the other side. Scientific knowledge has been explored and used to understand and likely foretell the dynamics within and movement of natural bio-physical elements in the ecosystem at the micro and macro levels. Although the existing scientific knowledge is sufficient to unfold what would happen if such an ecosystem is altered, due to the numbers of interrelated components in the system, together with the data required, computerized modelling has been widely employed to facilitate ecological studies. Another tool that has been utilized to deal with ecological complexity is the Geographic Information System (GIS) which includes maps and remote sensing data and software that can provide the related data and information needed for modelling and simulation, as well as visualize simulation results, and provides a comprehensive method to illustrate spatial consequences (Jessel and Jacobs, 2005; Scoccimarro et al., 1999; Bacic et al., 2006).

The critical aspect that makes NRM complex and difficult to achieve is the human dimension; each individual holds certain objectives and goals in directing his or her daily life, and these may change based upon the relevant surrounding conditions, both environmental and social. One important aspect that makes the human dimension different from the natural ecological context and dynamic is that humans can communicate with each other, and this source of information always influences decision-making. The decision-making of individuals or a group can be explained, but it is highly uncertain. Thus, social modelling has been explored and developed to gain a better understanding of the human dimension and explore trends that such individuals or groups may behave in line with, or how they respond to environmental and political changes (Gilbert and Troitzsch, 2005).

2.3 Modelling for Resource Management1

To understand the complex interactions between human societies and the land resources on which they depend, a growing number of scientists have turned to computer-based simulations. Simulations serve a number of purposes in the science of coupled human–natural systems, including: (a) providing integrated multi-disciplinary perspectives, (b) developing intuition regarding the causes of observed patterns and dynamics, (c) testing for the plausibility of candidate explanations, (d) developing conceptual frameworks for empirical data collection, (e) creating scenarios about future system states, and (f) testing the possible effects of alternative policy or management interventions in the system. In contrast to other modeling approaches such as cellular automata and Markov simulations, agent-based models (ABMs), under a multi-agent systems (MAS) concept, can explicitly formalize from simple to complex representations of the behavior and cognitive processes of actors who make land and resource use decisions within a system. Because the ABM approach explicitly represents actor behavior, these models may be viewed as more process-based and deductive than the statistical or mathematical models common in land change science, in which the emphasis is placed on fitting parameters to observations (Brown et al., 2004; Verburg et al., 2006). In designing an ABM, the modeler takes a 'bottom-up' approach by considering the relevant actors and decisions at the micro-level that may produce an observable macro-phenomenon such as a system-level outcome. The model development is guided by and compared to existing patterns in the target system that act as indicators of the underlying micro-processes and structure (Grimm et al., 2005). Therefore the use of an ABM approach to improve our understanding or support the rigorous analysis of the potential outcomes of a system, such as scenario and policy analysis, requires that ABMs have credible and defensible representations of micro-processes. This requirement raises important questions about available empirical approaches for capturing micro processes and their relative merits.

The aim of this section is to provide a review of the several data collection methods available, the types of data they produce, the types of questions the data can help answer, and the strengths and weaknesses of the data for use in an ABM approach. Five different approaches are recognized:

- Sample surveys
- Participant observation
- Field and laboratory experiments
- Companion modeling, and

[1] This section is based on a publication we co-authored, namely: Robinson D.T et al. 2007. Comparison of empirical methods for building agent-based models in land use science. *Journal of Land Use Science 2,* pp. 31-55.

- GIS and remotely sensed spatial data

These approaches differ on a range of dimensions, including the degree they rely on a priori theory, their ability to obtain social and biophysical data, the types of measurements recorded by each method (qualitative versus quantitative), their ability to elicit agent types, characteristics, beliefs, knowledge, and/or behaviors, the richness of the behavioral information they yield, and the degree to which they can capture temporal and spatial information. Each approach has its own (inter-)- disciplinary heritage. There are two distinguish reasons why ABMs need empirical data, these being: (i) to document the macro-phenomena, and (ii) to inform micro-process modeling. The projects discussed in this section use macro-level data for model validation, providing an independent test of the micro-level processes encoded in the model. This section focuses on the data requirements of micro-processes, because it is the representation of these processes that distinguishes ABMs from other modeling approaches. The five approaches discussed all generate data and an understanding at the micro level, that is, at the level of the decision-making agent), and such information has both qualitative and quantitative value when building models of agent-level decision-making. In qualitative terms, we might wish to test a hypothesized decision making strategy. Such tests provide generalized knowledge about strategies for decision-making, but rarely provide specific quantitative values that can be used in models. Other methods might be used to provide quantitative information about the relative value of various factors used in decision making, or about the relative abundance of various agent characteristics. The next will define and describe each of the above empirical approaches, and identify the questions they address and the kinds of data they produce. This session summarize each method with a listing of its strengths and weaknesses and describe an example case study in which each method was used. We conclude with a discussion on the comparative advantages of the different approaches, recognizing that each method has its strengths and weaknesses.

2.3.1 Sample Surveys

2.3.1.1 Definition and Description

Sample surveys are a quantitative method used to collect data on individuals, households and communities, using mostly closed questions. Typically, a fraction of the population is sampled using techniques (such as random and stratified sampling) that capture the distribution of characteristics found in the entire population. To provide a one-to-one representation of the real-world to software agents, most sample surveys are employed at the household level, since households are commonly the atomic unit of land use used in ABMs. Increasingly, household surveys and well documented data sets are becoming publicly available (Grosh and Glewwe, 2000; World Bank, 2005a, 2005b; IFPRI, 2005) and may serve as an input into ABMs in some contexts. However, modelers often need to design new surveys in order to tailor data collection to the needs of a particular model application or case study.

2.3.1.2 Types of Data Produced

Responses from sampled households are commonly used to parameterize behavioral models based on microeconomic theory, or to generate statistical descriptions of the attributes of agents in a population. Two approaches have been used in applying these statistical descriptions within ABMs. One uses Monte Carlo techniques to generate heterogeneous populations of unique agents (for example, Berger and Schreinemachers, 2006; Brown and Robinson, 2006). The other uses typical agents based on representative cases from the survey, in numbers proportional to their representation in the population (for example Deffuant et al., 2005; Happe, 2004).

2.3.1.3 Questions that can be Addressed using the Technique.

Household surveys can be used to:

- provide information on the distribution of characteristics, beliefs and preferences within a population of agents,
- estimate behavioral models based on economic theory,
- provide rough estimates of local-level change variables, and
- identify the constraints on decision-making.

2.3.1.4 Strengths and Weaknesses

The strengths and weaknesses of the sample survey method stem from its reliance on a restricted and structured set of questions about the characteristics and beliefs of agents and those of their neighbors. By restricting the number of respondents and questions, it is possible to produce quantitative data that is statistically representative of the broader population, without the expense of surveying all agents. The information that has been obtained from surveys can be used to cross-check observations and to assess the heterogeneity of households, and specialized household surveys can be used to map social networks of interaction. However, some information may be difficult to gather from respondents, as they may not know how to express themselves in a quantifiable way or may not wish to reveal certain information. Sample surveys can also be conducted with classes of agents other than households, such as company managers, providers of public infrastructure and policy-makers; however, such surveys are less common, and are often conducted with open-ended questions and interviews.

2.3.1.5 Case Study: Simulating soil fertility decline, population growth and poverty dynamics in Uganda.

Problem: Stagnating productivity and persistent poverty still characterize farming systems in much of sub-Saharan Africa.

Biophysical and social scientists tend to interpret the situation in widely different ways. Biophysical scientists point to soil fertility decline and population growth as the main causes and suggest technology improvement, while social scientists identify malfunctioning markets and institutions, suggesting corrective policy action. The objective of this study on Uganda (Schreinemachers, 2006) was to disentangle the combined effects of soil fertility decline, population growth and market institutions on the dynamics of poverty and productivity.

The twelve square kilometer research area included two densely populated villages in southeastern Uganda, comprising 520 households. Climatic conditions in the area allow for the cultivation of two sequential crops per year. Cassava, sweet potato, plantain and beans are the main subsistence crops, coffee is the main cash crop, and maize is both consumed and sold. The nearest town is around fifteen kilometers away, which provides good market access but only limited off-farm employment. Soil fertility is generally low but varies across locations. The landscape is gently sloping with large flat areas and moderate levels of soil erosion. Households typically are large, with more than nine members on average; they commonly rely on hand tools, rarely using fertilizers and improved seeds. Intercropping is common, and farm households usually allocate only small part of a plot to a single crop combination.

An ABM model, building on Berger (2001), was used to integrate biophysical models, simulating crop yields and soil dynamics, with mathematical programming-based economic models that simulated decision-making and poverty levels. Each real-world farm household was represented as an agent in the model. In line with micro-economic theory, it was assumed that three objectives guided agent land use decisions: cash income from selling farm produce and off-farm employment, in-kind income from consuming own farm produce and future income from investments in livestock and coffee (Schreinemachers and Berger, 2006).

In terms of data collection, various models of production and consumption behavior and the constraints on decision-making were estimated from the household survey data (Berger and Schreinemachers, 2006) and this was used to calibrate the mathematical programming model. The main components included econometrically estimated production and the model used freeware which can be downloaded (from http://www.uni-hohenheim. de/mas/software/). A manual is available from the same location. The model identified consumption functions and behavioral constraints relating to crop rotations, gender specific farm tasks, and input and output prices. These constraints were further specified with qualitative information from field observations and the relevant literature. Survey data proved suitable for this purpose, as all model agents were farm households and their land use decisions could be modeled by using well-established quantitative models of production and consumption behavior.

2.3.2 Participant Observation

2.3.2.1 Definition and Description

Participant observation is an anthropological research method in which the researcher both observes and participates in the target system. The aim is generally not to test a predefined theoretical model of how the system under study functions, but to build a conceptual model in line with field observations. Hypotheses are drawn from collected data and subsequently tested in the field; participant observation therefore involves building theory through iteration with observation (Strauss and Corbin, 1990). The technique of participant observation can support the building of ABMs by helping to identify the key agents in a system and by generating plausible explanations for the actions and interactions of agents. However, few papers have been published on its use (though Bharwani et al. (2005) is a useful example), and even fewer in the domains of land and natural resource use (Huigen, 2004; Huigen et al., 2006 are the only examples found).

2.3.2.2 Types of Data Produced

Primarily, participant observation produces qualitative rather than quantitative data. It can provide highly detailed information about interactions between individuals, about their motivations and perception of the world, and about the range of heterogeneity among these individuals, but is not likely to provide precision about the relative number of individuals having different characteristics. In some cases, participant observation can also generate simple quantitative data, based on counting 'everything you see', such as the number of households with gardens, or the amount of time people spend at a location. Much of the collected information is omitted in the final ABM, because the detail is too extensive to be incorporated, the hypotheses or experiments being tested are more focused, fewer mechanisms have been chosen to be modelled, or the model has been simplified to improve tractability and understanding. However, the very detailed information gleaned from participant observation is more likely to improve the model-builder's understanding of the forces driving the system, and of what they are leaving out, than when relying on statistical data, such as that collected by standardized living standard surveys.

2.3.2.3 Questions that can be Addressed with the Technique

Participant observation can help a modeller to determine:

- the driving forces in the system,
- how actors in the target system conceptualize their situation,
- the importance of contextual (e.g. cultural) and/or temporal dynamics,
- how individuals influence the social system, and vice versa, and
- the structure and functioning of local social networks, including the way that collective decision-making is carried out (an issue of great relevance to the construction of ABMs).

2.3.2.4 Strengths and Weaknesses

The strengths and weaknesses of the participant observation approach grow out of its intensive, on-the-ground requirements. Because the researcher is involved in the lives of those being studied, research is "pushed toward the scale of action". This naturally leads to a concentration on research questions relevant at that scale. The length of time the researcher spends with the group studied allows for the building of trust. This can help move beyond the tendency of informants to tell a researcher either what they think will be advantageous to tell them, or what they think the researcher wants to hear.

Also, the researcher's involvement in everyday activities makes it harder for stakeholders to withhold relevant information, and should increasingly allow the researcher to frame the right questions. Participant observation is highly dependent on the abilities, and to some extent the preconceptions, of the individual researcher. It is best suited to a relatively small spatial scale: a village, or a relatively self-contained community in a city. Given time to question and rethink hypotheses, participant observation allows the researcher a deeper understanding of the causal links between different aspects of the local situation.

2.3.2. 5 Case Study: The effects of land-use policies and programs on biodiversity conservation in San Mariano, Isabela, in the Philippines

For this research, the problem was an increasing population, decreasing land availability and the decreasing value of agricultural produce at the borders of the Northern Sierra Madre Nature Park leading to an increase of small-scale illegal logging as well as cultivation in the buffer zone and the national park. These illegal activities threaten biodiversity preservation and require mitigation through policy action. The goal of this study (Huigen, 2004) was to evaluate the effects of potential land use policies on illegal logging along the border of the largest national park in the Philippines. The study took place in the Disabungan River watershed, in the municipality of San Mariano, Isabela, in the Philippines. Thirteen barangays (villages) exist within the watershed, which are populated by various ethnicities that each has their own agricultural practices. Initially, settlers in the area performed slash-and-burn agriculture, which was then followed by permanent agricultural systems involving irrigated and rain-fed rice, yellow hybrid corn, bananas, and government programs inducing tree growth. The average farm is 1.5 hectares in size and most farming households are linked to a local crop-trader who provides them with credit for crop production.

An ABM was constructed using the MameLuke framework (Huigen, 2004). The model had three categories of agents: logging companies, crop market actors and farm households, and variations among the households were defined by ethnic identity and religion. Each ethnic group has different farming preferences, rules for decision-making and interaction, and strategies. The modeled farm households and crop market actors made land use decisions and interacted on a monthly basis, via a two-dimensional GIS landscape. The initial land use conditions of the landscape were established using remote-sensing observations and functioned as a starting point for scenario analysis. Several government land use program scenarios were then introduced, such as the development of irrigated areas, the introduction of agro-forestry, and market reforms. Other important scenario components that varied in the different models were demographics, including immigration control and family planning, and climate.

Data collection for the representation of (land use) decision strategies was conducted by participant observation. Researchers lived for extended periods with a number of farm households to understand their options and motivations for land use decisions. Using semi-structured interviews and progressive contextualization techniques, the researchers created a snapshot of the farmers' lives, which included ranking different actions. The Action-in-Context methodology (De Groot, 1992) was used to understand farmers' knowledge of potential options, their attitudes toward change and their potential behavior in the case of a change in context.

The overarching goal was to produce a numeric, behavioral representation of how social networks affect decision-making, along with cultural and economic motivations.

The data covered:

- ethnic differences with regard to the rules on where and when to plant which crop, and other farm system aspects such as labor investments and use of new technologies,
- ranking the preferences for crops (existing and potential) and future investments,
- learning mechanisms, that is estimating the farmers' thinking on the effects of governmental and NGO programs, workshops and other interventions,
- understanding household attitudes towards family planning issues, and
- identifying farmers' visions of changes and their behavior in potential future scenarios.

The numerous models contained one generic template for the behavioral and strategic aspects of the households with minor variations depending on the scenarios. This template consisted of more than 200 potential actions that were available to farm households who made land-use decisions in a changing social and physical environment.

2.3.3 Field and Laboratory Experiments

2.3.3.1 Definition and Description

Laboratory experiments have been used for decades in psychology, and more recently in economics (Camerer, 2003), and are beginning to surface in geography (Evans et al., 2006). In this paper it focuses on economic experiments that capture land-use decision-making behavior. The typical subjects in these studies are undergraduate students who obtain monetary or grade awards. Field experiments are less abstract than laboratory experiments, and can be adjusted so that they can be run in the field with resource users and villagers (Cardenas and Ostrom, 2004; Henrich et al., 2004). Because the contextual variables (such as culture and the presence of indigenous knowledge) are less tightly controlled, they result in noisier data. Both types of experiments are focused on understanding and testing alternative theories of decision-making. Participants are faced with a specific problem and certain rules, and the researchers observe the outcomes of the decision process and either observe or infer the way the participants go about solving the problem.

2.3.3.2 Types of Data Produced

The focus of controlled experiments is on the falsification of hypotheses and testing alternative models of decision-making, not on generating the data required for ABM development of a specific applied case study of land use. The experiments generate information on the decisions individuals taken in a setting where the monetary incentives are known. This detailed information on decisions can be used to fit behavioral models to the data, which provides evidence for the use of a specific decision-making strategy in an ABM to represent an actor in the target system. The goal is usually to keep the behavioral models as simple as possible, so that the results are general enough to be used in other contexts. Models that are simple yet comprehensive enough to fit data, can be applied qualitatively in situations where the decision-makers are similar to the subjects used in the laboratory and field experiments. The experiments provide information about the structure of the decision-making model, but the precise parameter values found may not hold in a different situation. Specific parameter values may depend on the empirical case itself, since the conditions in a case study are never exactly the same as those in experiments.

2.3.3.3 Questions that can be Addressed with the Technique

Typical questions that can be addressed with these experiments include the following.

- How are decisions about resource use made? Do subjects strategically forecast the behavior of others, or do they rely only on past observations?
- How do specific rules of the game affect resource use? For example, using different rules (treatments) the impact of communication can be quantified (Cardenas et al., 2000), and
- Which of a number of competing theories can best explain behavior? For example, which type of learning theory best explains how subjects learn to perform a certain task?

2.3.3.4 Strengths and Weaknesses

Because experiments can be designed to test specific hypotheses, they can help to develop general models of decision-making processes such as learning processes, decision-making on social dilemmas, preference utility functions and bounded rationality (see Castillo and Saysel, 2005; Deadman, 1999; Duffy, 2006; Jager and Janssen, 2002). Using different treatments, experiments can also test the effects of institutional influences, such as monitoring, incentives and sanctioning on individual and group behavior. Alternatively, the ABM can be used to predict behavior under new treatments (Goldstone et al., 2006). There are a number of drawbacks from using controlled experiments for use with ABM. Controlled experiments are focused on testing general models and theories of decision making. The output is a challenged and improved theory, not the empirical data needed to develop an ABM for a specific, applied situation outside the lab or field setting. Moreover, controlled experiments try to eliminate contextual and cultural factors, which might be the crucial factors in explaining observations in specific applications. Although there are many statistical tools used to test theories on experimental data, from an ABM perspective there are serious challenges to be met in order to test the suitability of models on different scales (Janssen and Ahn, 2006).

2.3.3.5 Case Study: Collective action of fishermen and crab hunters on Providence Island, Colombian Caribbean Sea

For the problem, Castillo and Saysel (2005) sought to formalize the behavioral theory of collective action in common property resource situations, where collective action is required to reduce resource depletion by self-interested actors (Ostrom, 1998). The theory includes assumptions on relationships between face-to-face communication and the development of norms, and relations between trust, reciprocity, reputation and cooperation. Fish and crab resources are essential to the livelihoods of the inhabitants of Providence Island, in the Colombian Caribbean Sea. Black crab production had increased over the fifteen years prior to the study, in order to satisfy both trade and tourist demands. Depletion of the fisheries had caused observable increases in labor inputs, and more extensive harvesting by the fishers.

Castillo and Saysel (2005) developed a systems dynamics model based on the behavioral theory of collective action. They formulated causal relationships among the components of the theory, through feedback loops, representing the interactions between trust, reputation, and reciprocity among the residents. The model operated at the individual level, whereby a five-player real-life setting was represented as five artificial decision-making agents. These agents were either homogeneous or heterogeneous; however, the model was run separately for different categories of agents, such as fishers and crab hunters.

The model was calibrated using experimental data. The experiments used traditional common pool resource settings where a group of five villagers played ten rounds without communication and external regulation, and then ten rounds with one of the two different treatments. The subjects were recruited from fisher and crab-hunter communities. The experimental subjects had the opportunity to harvest from a virtual common resource, though there was a discrepancy between the individual and collective interests, when measured in monetary incentives. The two different treatments in this experiment were communication and punishment, thus in half of the experiments the subjects were allowed to communicate between each other - during the last ten rounds of the experiment. In the punishment treatments, each round-one player was chosen randomly and received a penalty when he or she harvested more than was allowed. The experiments with communication converged towards a cooperative solution, while punishment performed well initially, but over time produced movement away from cooperative behavior. Simulations using the model were able to replicate the experimental data for the communication and punishment treatments. Additionally, a rigorous analysis was performed to test whether the developed model was robust for more extreme conditions and assumptions. The model was found to be structurally robust and the theory of Ostrom (1998), as implemented by Castillo and Saysel (2005), was found to be a plausible model of the behavior of the fishermen and crab hunters on Providence Island, off the Colombian coast.

2.3.4 Multi-agent Systems and Natural Resource Management

The MAS approach and computational modeling techniques have been progressively developed to explore and understand individual behavior and interaction among agents and the environment, in order to represent the complexity of the whole system (Gilbert and Troitzsch, 2005), and have been increasingly used to deal with ecological and socio-economic issues arising from the management of scarce resources by multiple users. Integrating MAS with other biophysical or economic models and spatial database tools can enhance the adaptive learning capability of all stakeholders regarding their role and effects on ecological system dynamics. This has tremendous potential for assisting decision-makers in understanding and managing landscapes (Gimblett, 2002; Parker et al., 2003; Le Page et al., 2001).

In the field of common-pool resource management, many studies have focused on the use of adaptive management to deal with complex situations, with the assumption that enhanced mutual understanding brings about better coordination and greater collective ability, thus strengthening the adaptive capacity of stakeholders who take part in resource management (Lansing and Kremer, 1993; Trébuil and Bousquet, 2003).

The ideal MAS model, one applicable to watershed resource management problems, should include and dynamically link social and biophysical subsystems on multiple levels, and provide sufficient precise intervention scenarios to support the experimental discovery of potential intervention strategies that appear effective in achieving cooperative management among watershed stakeholders (Doran, 2001). Several studies have provided promising methods for the integration of MAS and other tools, in order to enhance decentralized and adaptive resource management. In one such study, stakeholders were included and allowed to participate in a research process called "companion modeling" (Bousquet et al., 1999). This approach aims at empowering grass-roots stakeholders through the acquisition of a clear understanding and a long-term vision of their system dynamics, allowing them to cooperate and manage their natural resources collectively (Barreteau, 2003; D'Aquino et al., 2002). This enhances and facilitates research in order to understand complex phenomena and to develop, modify, and validate models through stakeholder participation. Moreover, this also changes the traditional relationship between the researcher and other stakeholders.

The unified modeling language (UML) is commonly used in conjunction with object-based models because it has mechanisms to communicate the structure, processes and rules that drive model outcomes. UML has now become the standard for object-oriented modeling and design, as it is in the MAS model (Fowler and Scott, 1999). The static class diagram in UML is widely used to enhance the process of identifying agents and their behavioral characteristics, functions, and relations to other agents. UML can be extended to develop events and sequences of models, which thus supports processes of programming, verifying, and redesigning models (Liang, 2003).

Recent MAS applications have employed UML as a means of facilitating communication among model designers and programmers. This seamlessly becomes a standard protocol among researchers belonging to different disciplines and having various experience in developing computerized MAS models, such as among the participants in MAS training courses held in Thailand during 2001 to 2003 (Parker et al., 2003; Trébuil and Bousquet, 2003).

2.3.5 Companion Modelling

2.3.5.1 Definition and Description

Companion modeling was developed in the context of adaptive and collective ecosystem management, which is aimed at both increasing ecosystem adaptability and accounting for social processes that cause a particular ecological state. First, an initial model is constructed based on a virtual world that is mapped and parameterized from field studies, surveys and literature. The initial model is constructed as a physical representation where stakeholders can alter the environment and observe the alterations made by others. This interaction often creates its own rules and dynamics. Next, role-playing games (RPGs) are designed to make use of the virtual world and to collect information about the perceptions of stakeholders concerning the situation depicted in the model, including decision-making rules and behavior. Finally, the output from the game is analyzed to verify or modify processes within the model, and for the purposes of encoding agent behaviors within a computerized ABM. The rules and structure of the RPG are often simplified to promote player understanding, while ABMs capture greater detail. Together they serve as shared representations of the target system and as tools to simulate scenarios with stakeholders (Bousquet and Trébuil, 2005).

2.3.5.2 Types of Data Produced

The RPG and post-game interviews provide data on stakeholders' decision-making processes and behavior in the defined problem domain. To minimize error, individual interviews and group discussions are used to cross-check researcher interpretations of what the players did during the game and why. These decision-making processes are transformed into rule-based agents appearing in the ABM. Far more than in any other approach, changes in the perception and the future action of involved stakeholders are to be expected during the model-building process, because their understanding of the situation might change through the RPG, and the interaction with the ABM and the researchers.

2.3.5.3 Questions that can be Addressed with the Technique

Specific research questions depend on context and are subject to evolution and modification during the research process, as new questions or hypotheses can be added. In general, companion modelling can help modellers to: analyze the interactions among actors, their institutions, and the natural environment; evaluate the process of collective decision-making as observed within the RPG context; and improve the stakeholder's knowledge of the diversity of perceptions and beliefs held in the community.

2.3.5.4 Strengths and Weaknesses

In most cases companion modeling requires a multi-disciplinary research team that includes both natural and social scientists. Sometimes it is difficult to define the exact task and role of the researcher, which may range from facilitator to mediator, observer or stakeholder. RPGs are very costly, time-consuming and difficult to set up when there are serious social and political conflicts between stakeholders. However, the RPG can elicit tacit knowledge since, within a particular environment and game, a participant may base responses on individual knowledge that he or she may not be able to express in other acquisition methods. The quality of data depends heavily on the quality of the selected stakeholders who play the RPG and how well the researchers can assess the interactions that emerge during the game. Also, some games allow open communication and interaction among players, and it is often too difficult to record every action and contextual variable. To maintain understanding, game sessions are limited by the number of players and rounds of play. Unfortunately there is always a risk of failure, even if the game is pre-tested, because players may have varying degrees of willingness to participate and varying motives or reasons for participating. However, failure of a session does not necessarily mean the failure of the RPG itself, as the RPG may reveal new approaches, methods or issues that would engage stakeholders in the companion modeling process. Also, in the event of a failed RPG, researchers still derive new insights into the problem being investigated by the increased interaction among stakeholders and researchers.

2.3.5.5 Case Study: Access to Credit in Northern Thailand

Collective learning is evolutionary; solving a problem might raise a new one. This is what happened when an experiment conducted in the highlands of northern Thailand sought to address a soil erosion problem (Trébuil et al., 2002) and discovered the real issue was access to credit. Ethnic minorities located in these highlands were accused by the Thai Government of generating soil erosion and were threatened with restricted access to land. To solve the problem, companion modeling was used to stimulate a learning process on this issue, within a community of highland farmers. The participants identified perennial crops as a promising solution to limiting soil erosion while securing higher and more stable incomes, but they also raised a social equity issue; in which many poor small land-holders did not have access to credit for investment in perennial crops. This case study is focused on the latter issue associated with credit access, and the subsequent effects of credit access on crop choices and soil erosion (Barnaud et al., 2005).

For this study, the physical system was a 369 hectare watershed, containing the Mae Salaep village in Chiang Rai Province, northern Thailand. Over the last two decades, Mae Salaep farmers have integrated into the market economy, and their former farming system based on swidden cultivation has been replaced by permanent and cash crop-based agriculture. These changes have led to an extensive socio-economic differentiation among farming households holding different amounts of resources and having different socio-economic interests and land use practices. Informal and formal credit systems co-exist in the village and were represented in the model. Informal credit was given and taken among villagers, via social networks or informal money lending contracts. Formal credit was available through government sources, but was only accessible to well-off households. This unequal access to credit was only partially compensated by its redistribution through informal loans within networks of acquaintances.

In the model, as in the game, the players search for and/or pay back credit each year if needed, making decisions regarding off-farm employment, allocating crops in their fields, harvesting products and selling them in the market, and paying family expenses. The spatial interface was a reproduction of the gaming board, that is, a simplified representation of a small watershed with various slopes and small squares representing farmers' plots. The main agents in the model are twelve farmers with various amounts of resources, corresponding to the twelve players in the RPG. In the model, farmers' decision-making processes are represented, whereas in the game, players make decisions themselves. Likewise, networks of acquaintances are also represented in the model that are not explicitly represented in the RPG. The model was used to explore with the villagers various scenarios suggested by them, with new rules of allocation of formal and informal credit.

Data collected through participant observation and semi-structured interviews was used to conceive and calibrate agent behavior of the first model and the RPG, focusing on erosion. A second set of field interviews were conducted on the request of the participants to analyze the interaction between the adoption of perennial crops and access to credit. The RPG sessions allowed the researchers to validate and to better understand farmers' behavior as it revealed tacit knowledge about the credit system. In addition to observing participant behaviors during the gaming sessions, post-RPG interviews clarified this behavior and assessed villagers' perceptions of how closely the game corresponded to the way they perceived reality. The collective discussions with local stakeholders stimulated by the use of the model provided information about people's preoccupations and were used to adjust the model accordingly.

2.3.6 GIS and Remotely Sensed Spatial Data

2.3.6.1 Definition and Description

A wide range of spatially explicit data has become available on various aspects of land use and land cover. This spatial data is extremely useful for deriving input variables that reflect the drivers of land use suggested, for example, by the Von Thünen and Ricardian theoretical frameworks. These frameworks suggest that both accessibility to markets and biophysical suitability influence land use. Spatial data may also reveal important influences on decision-making outside market contexts. For example, neighborhood relationships may affect technology adoption (Berger, 2001; Case, 1992), and local accessibility may affect the probability of forest conversion (Mertens and Lambin, 2000; Deadman et al., 2004). Spatial data can be analyzed using spatial statistical inference methods. A goal of this approach for supporting empirical ABMs is to analyze land use histories in order to test hypotheses about relationships between agent decisions (such as land-use change) and a range of spatial and contextual variables, and to establish quantitative parameters for those relationships. A number of analytical methods are available for pursuing this approach, including panel data analysis (Hsiao, 1986; Seto and Kaufmann, 2003), survival analysis (An and Brown, 2008), and multivariate limited dependent variable models (Mertens and Lambin, 2000; Parker and Munroe, 2007).

2.3.6.2 Types of Data Produced

Spatial data can be used to derive maps of physical networks (for example, waterways), mobility impedance (or friction) surfaces, biophysical characteristics (such as soil), demographic variables, political and institutional boundaries, land use and land cover. This data can then be used as an input into ABMs, in maps of the environment within which the agents interact, through derived measures such as travel costs or neighborhood relationships that may serve as inputs to agent decision models, or through spatial statistical modeling to calibrate agent preference or behavior parameters that describe agent–environment relationships.

2.3.6.3 Questions that can be Addressed with the Technique

Spatial data inputs are most suited to answering questions about the relationships between factors external to the agents and the agent decisions, where the agent decisions are readily observable. Such questions can include:

- What is the relative influence of biophysical factors, such as soil fertility, on the probability that an agent will convert from one land use to another?
- How do biophysical factors interact to affect particular decisions?
- How do neighborhood characteristics affect decision-making? and
- How do spatial relationships vary over time and space?

2.3.6.4 Strengths and Weaknesses

Spatial data is often readily available, often inexpensive, can cover large geographic areas, and may extend to include historical conditions (e.g. remote sensing). Because the method relies on inference from existing data, it is limited to questions that involve existing data, and requires a pre-specified set of hypotheses; there is no mechanism to discover new decision-making frameworks or structures. In particular, actions, characteristics and motivations of human actors are rarely directly revealed through data on spatial outcomes. A host of other issues also exist, such as those associated with matching the scale of spatial data to the scale of agent decision-making

(Liverman et al., 1998), disaggregating data to inform agents (the ecological fallacy; Schuessler, 1999), unobserved variables driving the underlying processes - non-stationary in time and space, the fact that observed land use outcomes may be the result of competition between multiple agent groups, and incongruity between the observations used to fit the statistical model and the agents in the ABM.

2.3.6.5 Case Study: Interacting agents, spatial externalities and the evolution of residential land use patterns

The problem for this study was that recent changes in urban land use patterns in the United States had been characterized not only by urban decentralization and the formation of new suburban sub-centers, but also by low density, fragmented residential development in outer suburban and urban–rural fringe areas. The traditional bid–rent model based on transportation costs to the central city fails to explain the observed fragmentation of the residential land use pattern. A study by Irwin and Bockstael (2002) aimed to investigate whether the repelling effect of negative interactions, for example due to congestion externalities, offers an agent-level explanation for scattered development. The analysis used georeferenced data on land parcels from an ex-urban region of central Maryland in Washington D.C. the United States, as the major urban center in the study region.

Agents were rural landowners associated with an individual parcel of land and thus fixed in space. Agents were assumed to be profit maximizers and would thus respond to underlying market forces that influence the relative net returns of converting their parcel to development. The probability of parcel conversion was related to factors that included proximity to major urban centers, which was hypothesized to bid up the returns to development; zoning restrictions, which were hypothesized to depress the potential returns to development; parcel characteristics influencing conversion costs, such as steepness of slopes; and the opportunity cost of developing the parcel, which was approximated by its soil type, because better farmland had a higher opportunity cost associated with it. To represent neighborhood interactions, the percent of developed neighboring land within a certain distance was measured for each developable parcel to capture the potential spillover effects of neighbors on a parcel's conversion probability. A constant regional demand for new housing was assumed, and the parcel with the highest probability of conversion in each time period was chosen for conversion, where a time period was arbitrarily defined as the period long enough for one conversion to take place. To account for the changing landscape, neighborhood interaction effects were recalculated after each predicted conversion for the unrestricted case.

A GIS database on land use, values, suitability and accessibility was developed from publicly available data sources. A Cox's proportional hazards model was estimated using all parcels that could have been converted to residential land use as of 1991, based on the year in which subdivision of an undeveloped parcel took place between 1991 and 1997. Furthermore, the estimated hazard rate of parcel development was a function of the relative amount of neighboring development and the other explanatory variables. Estimated parameters from the statistical models were used in the simulation model in two forms: the unrestricted model, in which an interaction effect was accounted for, and a restricted model, in which the interaction effect was set to zero. Simulations using both the full and restricted models' estimated parameters were carried out for multiple development events, and the results were then compared with the actual pattern of sub-division development that occurred for a given sub area of the study region. The simulation results showed that the inclusion of the negative interaction effects generated a pattern that was significantly more fragmented and one that appeared to mimic more closely the actual pattern of residential sub-division development. Based on this evidence, the authors concluded that the estimated negative interactions effect among landowners was sufficiently strong to cause a repelling effect among developed parcels.

2.3.7 Discussion

Multiple methods exist to gather data on micro processes for land use systems. Since these systems are composed of multiple actors that interact with each other and their environment in complex ways across space, time and scale, ABM provides one formalism for integrating the many elements that comprise the land use system (Parker et al., 2003). We identify the following key questions that should be answered about the micro-processes of an ABM designed to explore questions relevant to land use science:

- Social and biophysical environment.
  - What environmental or social factors influence actor decisions? and
  - What are their relative strengths of influence?
- Agents
  - What are the primary classes of actors and how many are there of each?
  - Who interacts with whom (type of interaction, frequency and conditionality)?
- Agent behavior
  - What decision models and cognitive processes do actors use to make decisions?
  - Do actors adjust their decision making or learn—if so, when and how?
  - What differences exist between actors with regard to these processes?
- Temporal aspects
  - What is the sequence and duration of agent actions and interactions, event occurrences, and information updates for agents?

Each of the five empirical methods (sample surveys, participant observation, field and laboratory experiments, companion modeling, and GIS and remotely sensed spatial data) has comparative advantages and complementarities for informing these ABM components. While our discussion focuses on a comparison of the empirical methods for informing each of these components in land use ABMs, other axes of measurement and comparison exist (Agarwal et al., 2002; Parker et al., 2002; Janssen and Ostrom, 2006; Parker et al., 2008).

There is no perfect single data collection method that can inform all aspects of a complex ABM of land use and land cover change. Each method is different in its focus. For example, surveys target individuals' characteristics, constraints and the previous decisions of households; field and laboratory experiments target individuals' behaviors in a controlled setting; companion modeling targets group dynamics; participant observation reveals the contextual factors influencing individual and group decision-making; and spatial data analysis focuses on social and biophysical characteristics encoded into the landscape. Graphing the methods according to the ABM components listed above provides a comparison of the capability of each empirical technique for obtaining information on (a) biophysical versus social systems, (b) quantitative versus qualitative descriptions of agent characteristics and behavior, (c) agent interaction versus learning, and (d) temporal versus spatial information. While the placement of each empirical approach on the axes could be considered subjective, we have reached a general consensus among the co-authors regarding their relative positions to each other. The graphs provide a much needed holistic view of how different types of empirical data inform ABMs and how the different approaches compare relative to each other. Next we compare each approach for informing the ABM components listed above.

<u>Social and biophysical environment:</u> for this, spatial data is the most readily available and abundant source of multi-date data on the spatial heterogeneity of the biophysical environment. However, like surveys and field and laboratory experiments that are constrained by their structure of questioning or testing, it is extremely difficult to identify new processes or their underlying processes using spatial analysis methods. The flexibility of participant observation and companion modeling provide a more detailed representation of the social environment, and can identify social networks that may influence actor decisions. However, spatial data, like surveys, provides quantitative measures of outcomes of agent behaviors through the quantity and location of social and environmental changes across the landscape; whereas the other methods produce qualitative interpretations.

<u>Agents</u>: our ability to identify types of agents, the abundance of a type of agent, the proportion of the overall population that is composed of different agent types, and variation in agent characteristics within a single type of agent acting in a target system, is dependent on the scope and scale of analysis, as well as the degree of heterogeneity one wishes to capture. Heterogeneity, through agent categorization (that is, types of agents) and variation (that is, continuous variation in the characteristics of agents; Brown and Robinson, 2006), is a central component of most ABMs because it influences adaptation (Axelrod and Cohen, 2000) and acts as a trigger initiating different behaviors among agents within an ABM (Holland, 1995). Each of the empirical methods addresses one or both aspects of heterogeneity to identify the types and characteristics of the agents that represent the actors in the target system. Empirical data collection by

surveys is guided *a priori* by theory and therefore the researcher often develops questions and structures the survey to target specific actors in the target system. In the Uganda case study discussed above, a survey of all farming households obtained extensive quantitative information on the characteristics and heterogeneity of those households. However, subsequent sub-division of households into multiple household (agent) types was imposed based on interpretation by the researchers and their analysis of household characteristics derived from the survey. In some cases the defined agent types may not have any relevance to those agents acting within the system (Axelrod and Cohen, 2000). Similar to surveys, the use of field and laboratory experiments, and GIS and remotely sensed spatial data to obtain information on agent types, abundances and variation within types, is highly constrained by the theory guiding experimental design and spatial analyses. Therefore, like surveys, these methods also trade-off the ability to identify agent types for increased knowledge of agent variation. Furthermore, spatial data rarely ever directly reflects agent characteristics. While spatial analyses are strictly quantitative, experiments involve a great deal of qualitative measurement, especially when trying to identify and compare decision models, and decision making behaviors and reasoning. In contrast, through participant observation, Huigen (2004) identified different farming practices and behaviors in the Philippines based on ethnic and religious background of farming households. However, participant observation in itself was not able to quantify variation in the demographic, socio-economic, and network characteristics of the actors, as well as the landscape within which they were situated. Thus, qualitative characteristics (such as high- or low-income earners) provided heterogeneity and variation among agents in the developed ABM. The qualitative nature of participant observation may also identify benchmarks that act as guiding principles when defining the range of an agent characteristic. Companion modeling provides a special case, whereby agent heterogeneity is initially guided by surveys, literature and existing data for the initial design of the RPG, but the highly iterative and adaptive nature of the game permits further identification of agent categories. Like participant observation, companion modeling primarily produces qualitative data. Because companion modeling often has a one-to-one representation between agents and actors in the real system, there are often a small number of participants and therefore much of the heterogeneity of actor/agent variation is lost or simplified in order to maintain a comprehensible model for stakeholder participation. Both participant observation and companion modeling can be used to develop theory.

Agent behavior: it was extremely difficult if not impossible to validate the correspondence between the structure of the actor's behavior in the real system and our agent-based representation of that actor in our ABM (Couclelis, 1986). Instead, we were forced to observe the outcomes of actor behaviors and fit our behavioral models to that data. While some empirical data collection methods are better at testing alternative behavioral models (for example, laboratory and field experiments) others are better at identifying thresholds or ranges influencing a change in the behavior of an actor (such as surveys). Typically, agent behavior is described based on the type of behavioral model implemented in an ABM, such as heuristics (Deadman et al., 2004); optimization or utility maximization (Caruso et al., 2005; Schreinemachers and Berger ,2006); bounded rationality (Arthur, 1994); satisfaction - beliefs, desires and intentions; and evolutionary processes (Reschke, 2001). However, to frame our discussion on empirically informing agent behavior, we define three classes of behavioral models: (1) decision-making, (2) learning, and (3) adaptation models. The level of complexity increases with each class, respectively, and the data required to inform each model differs.

Heuristics: decision-making behavior includes all functions that transform a stimulus into a response. In the case of heuristics, simple 'IF . . . THEN' clauses are often used to describe the outcome behavior of a stimulus. The dynamic and repeated observation and logging of actor behaviors under different scenarios by participant observation and companion modeling, makes them well-suited to derive 'IF . . . THEN' heuristic information. To a lesser extent, experiments are also able to derive 'IF . . . THEN' types of decision-making behavior; however, experiments are more abstract and may be better suited to general and qualitative questions. It may be possible to obtain quantitative data from surveys to define ranges or thresholds whereby actors change their behavior in the target system. However, gleaning this information from GIS and remotely sensed data is much more difficult.

Optimization: a utility value or fitness measurement can also be used to evaluate potential decisions. If the agent has complete information and can select the behavior that maximizes his or her utility among all possible options, then the model incorporates completely rational agents. If the agent attempts to maximize utility over some constrained range of options, or achieve a minimum level of utility, then the model incorporates bounded rationality or satisfaction, respectively. Survey data are particularly well suited to obtaining preference information influencing agent decisions. However, the predefined structure of sample surveys methods tend to be poor at identifying the underlying mechanisms driving landscape patterns, such as the decision-making approach (such as profit maximizing versus satisfaction), agent learning, or agent interaction. In contrast, experimental methods are well suited for testing alternative theories of decision-making. Preference data can also be ordered, ranked or measured from survey collection methods to develop weights that are applied to stimulus factors in the behavioral model used by an agent. Similarly, if laboratory and field experiments are designed for a specific problem, this type of quantitative data may be obtained. Utility functions and calculations derived from participant observation, companion modeling, and GIS and remotely sensed data are subject to greater uncertainties and are not recommended as data collection methods for this behavioral approach. While decision-making involves transforming a stimulus into a response, learning adds an additional level of complexity by incorporating memory. Some agent behaviors incorporate learning in the form of mimicry, experimentation or self-reinforcing behavior among others. Learning may permit an agent to improve performance and efficiency to exploit a specific behavior under a given environmental and socio-economic context, but this may also cause the agent to be harmed if the situation changes and he or she has not explored alternative behaviors or strategies (March, 1991). Directly measuring learning is difficult but possible using each empirical approach. For example, surveys can question how long a respondent had knowledge of a potential crop before it was adopted for plantation; participant observation may ask such a question verbally, or record the number of times a visitation (reconnaissance) occurred between an early adopter and a laggard before the laggard adopted. In companion modeling, researchers can test out different types of information diffusion strategies and measure the relative adoption rate among actors. As far as we are concerned, with land use and land cover change decisions, a multi-temporal analysis using GIS and remotely sensed spatial data can derive the adoption rate of new farming practices or crops chosen among a community. Laboratory and field experiments are perhaps best suited to identifying the structure of the learning process where the repeated decisions of actors are recorded (Evans et al., 2006). Because these experiments test alternative models in controlled settings, they provide the least amount of discrepancy between the conceptually defined ABM and the operationally defined experiments. While the contextual variables that are identified by companion modeling and participant observation approaches assist the modeler to better understand the target system, most of this data is rarely entered into the ABM. However, both methods are useful for identifying agent behaviors, and when participants are allowed to reflect on their choices, agent motivations.

Temporal aspects: the data collection methods listed above rarely address issues related to the timing of agent actions in an absolute sense (such as the timing of a decision, especially in relation to timing of potential drivers), in a relative sense (agent A does not make a decision until agent B has made one), or in an evolutionary sense (that is, how do agents' decisions change over time in response to changing internal and external conditions?). Various temporal aspects of decision making may be implicitly assumed based on the conceptual model. For example, if a land-use model of a residential location is demand-driven, then the residents will make decisions before developers; if the model is supply driven, then the opposite will likely occur. We are still ill-equipped in our data collection methods to define the frequency, duration and order of agent actions, agent decision-making processes and event occurrences over time. Perhaps the most important issue in using data collection methods to support ABM is that modeling is a process that involves an iterative cycle of observation, modeling, prediction and testing. This process may involve multiple data sources (especially to ensure separation of calibration and validation data) and development of multiple models. Clearly the best way to empirically inform an ABM is to use some combination of approaches. The examples given of participant observation and companion modeling illustrate this point. It is also evident that some combinations may prove more useful than others.

2.4 Integrated Participatory NRM in Northern Thailand's Watersheds

From the late 1980s to the mid-1990s, an impressive number of influential highland development projects were implemented in the northern Thai highlands. These projects aimed to suppress narcotics production and promote sustainable-cropping practices that could also contribute to improving the tribal people's well-being and halt the amelioration of natural resources. In the early phases of implementation, most of these projects focused on introducing technological packages; however, they failed with this top-down development approach. The United Nations led Sam Mun Highland Development Project (UN-SMHDP) was one that adopted and integrated a participatory development approach, followed by the Thai-Australia Highland Agricultural and Social Development (TA-HASD) project, the Thai-German Highland Development Programme (TG-HDP), and many other projects. Various participatory techniques and tools were applied to accompany problem analysis, plan alternative resource management, and finally establish collective rules and actions for watershed management. Examples of this were group seminars, three-dimensional topographical models (3-D model), rapid rural appraisal (RRA), rural system analysis (RSA) and participatory rural appraisal. All the projects aimed at seeking cooperation and collaboration among key stakeholders through participatory approaches. At the same time, non-government organizations (NGOs) implemented development projects to encourage local people to collectively organize, analyze their situation and problems, make plans and take action. However, they experienced difficulties because of insufficient cooperation from government agencies, and there was no law to support the right of local people to manage their local natural resources (Missingham, 2001; Puginier, 2002).

An example of the success and failure of integrated highland development projects is the UN-SMHDP, which was initiated to end opium cultivation but in the 1990s was concerned with watershed preservation (Gillogly, 2004). This had profound consequences for the minority peoples who lived in the forested mountains. Almost the entire region of the SMHDP was on Class 1A watershed land; therefore, all residents were considered illegal occupants and were vulnerable to even indirect threats of removal from the land. The SMHDP had developed its own unique methodology to create a sustainable rural economy for people in the mountains. Crop substitution strategy which was applied before, failed due to its dependency to the lowland market, the price declined, then the villagers expanded the land to produce more in order to catch up with low market prices. The SMHDP resolved to turn people from seeking a profit to a path of subsistence, self-reliance and moderation, thus achieving economic and social security. It sought a diverse mix of annual and perennial crops that would provide a steady source of income the year round on a limited amount of land. It discouraged dependence on extensive monocropping and carefully vetted any companies that wanted to contract land and labor to grow crops.

The project also joined with Chiang Mai University (CMU), a northern Thai university, who had developed a methodology called Participatory Land Use Planning

(PLP). PLP depended on the collaboration of agriculturalists, foresters, social scientists and local farmers themselves, to identify the specific needs of each locality. One of the first elements was to pinpoint the differing interests of the parties involved. To the foresters and policy-makers in Bangkok, the issue was about conservation of trees, and thus of watersheds; to the farmers, it was about land for cultivation. The PLP sought a compromise between these competing interests by improving communication among the parties. Both PLP and SMHDP required placing extension workers in villages for several years. In this way, villagers and extension workers learned to share knowledge. They then jointly developed land-use maps that were transferred to 3-d maps of the area. In building these models, foresters and villagers constructed the vocabulary and social relationships meant to facilitate communication and understanding of each others' ideas. Finally, based on these maps and the better understanding of each others' positions, they developed a land-use planning system that was enforced by villagers themselves. This methodology proved extremely effective, at least on a small scale within the SMHDP. But the government officials thought it had taken too long to get results; they were oriented toward the "efficient" adoption of quantifiable goals, and they felt PLP was prone to "inaccuracies", that is, the incorrect understanding of local upland farmers. Therefore, they turned to focus on GIS, the main goal of increased communication was corrupted and what had been a community-based participation effort was transformed into a mechanism of government control.

SMHDP has become a pilot site for the testing and refinement of these GIS technologies, for use on Thailand's northern borders to monitor poppy cultivation and agricultural use. The reasons stated for the superiority of GIS are interesting. They include greater specificity and precision of information – though in this project current watershed classifications were based on 25-year-old maps with too large a scale to be useful on the ground, then, the building of a 3-D map was ended. The Government tried to get around this by building 3-D maps on the basis of GIS-generated maps. Farmers' contributions included disclosing the locations of their fields to government officials and then receive instructions as to what they could and could not do. One of the goals of GIS in this case was to make watershed classifications more accurate with respect to actual conditions on the ground, so that the blanket banning of cultivation in the mountains could be changed, which had the potential to work to the highlanders' advantage. However, the highlanders lost control over the process; what they got was a project that hoped to offer them "appropriate" plans that would result in greater compliance. After the Asian Financial Crisis in 1997, the Thai Government faced a huge budget deficit and there was little money to continue inputs into social development projects. Furthermore, the SMHDP's main fundings were lost when the UN pulled out of Thailand in 1995.

An integrated water resource assessment and management (IWRAM) project was conducted in five sub-catchments in northern Thailand after late 1997. This project tried to involve all three keys government agencies in the process of adaptive decision-making (ADMP). However, only the Land Development Department (LDD) was incorporated within the project. The project developed an integrated decision-support system (DSS) by linking a biophysical module (hydrology, crop growth and soil losses) with a socio-economic decision module to allow land managers (for example, the LDD and the Royal Forestry Department, RFD) to assess the implications of alternative water resource management scenarios. However, this was not a fully decentralized dynamic model, since individual household decisions were aggregated at each sub-watershed level. Most of the model conceptualization, design, development, and validation phases were implemented by the researcher (Letcher et al., 2002; Lal et al., 2002).

Becu et al. (2003) developed CATCHSCAPE, a MAS model using the CORMAS (common-pool resources for multi-agent systems) platform, to simulate scenarios of resource management processes of land-use and hydrological dynamics of a catchment in northern Thailand. They used stakeholder elicitation techniques in digesting key perceptions of farmers toward agricultural practices related to water use to be used in model design and development. This model emphasized farmers' individual decision-making based on different viewpoints, regarding household resources and land and water management, without interventions from local and government institutions.

Trébuil et al. (2003) conducted participatory research to test the companion modeling approach by associating MAS, geographic information systems (GIS) and role-playing games to enhance collective learning processes among stakeholders whose activities and interactions affected resource dynamics in a highland and market-integrated watershed of upper northern Thailand. The initial prototype model developed by the research group evolved iteratively between researchers and stakeholders, through role-playing game sessions simulating a simplified version of the computer model, followed by individual interviews and group discussions (Trébuil et al., 2005). Thus, the resulting model provides an acceptable common representation of agricultural dynamics in this watershed system, and it allows stakeholders to experiment and assess land management scenarios. This kind of work is seen as being very useful for facilitating negotiation, mitigating conflicts and enhancing collective land resource management. This promising approach and tool can be adapted to incorporate other key government agencies and local institutions to participate in desired decentralized natural resource management.

Puginier (2002) illustrated and assessed local land-use planning for natural resource management at the village level in Mae Hong Son Province, northern Thailand. GIS and remote-sensing tools combined with participatory tools were used to collectively delineate a mutually agreed-upon land-use boundary and land-use plan among local people, key government agencies, and the *Tambon* Administrative Office (TAO). The result of this study revealed that the Tambon level is a suitable scale for creating a communication platform for stakeholders to collectively participate in desired land resource planning. However, government agency cooperation and the right of local people to manage their natural resources are needed to carry out these tasks.

Table 2.4 summarizes the various levels of the key stakeholders involved, and the tools and methods used in different research and development projects that have dealt with highland development and natural resource management in northern Thailand.

Table 2.4: Projects and research projects with different stakeholders, area scale, and methods and tools

Project/research[a]	Stakeholder[b]	Implementation level	Methods/tools[c]
UN-SMHDP, TA-HASD, TG-HDP, NGO	Local organization	Watershed	3D model, RRA, RSA, group meeting, networking
IWRAM	LDD, RFD	Watershed	Biophysical and socioeconomic model
Becu et al. (2003)	Local people	Watershed	Stakeholder elicitation technique, knowledge engineering, MAS
Trébuil et al. (2002)	Local people	Watershed	GIS, MAS, role-playing games
Puginier (2002)	Local people, TAO	Village	GIS

[a] UN-SMHDP = United Nations - Sam Mun Highland Development Project, TA-HASD = Thai-Australia Highland Agricultural and Social Development, TG-HDP = Thai-German Highland Development Programme, NGO = nongovernment organization.
[b] LDD = Land Development Department, RFD = Royal Forestry Department, TAO = Tambon Administrative Office.
[c] RRA = Rapid Rural Appraisal, RSA = Rural System Analysis, MAS = Multi-Agent System, GIS = Geographic Information Systems.

CHAPTER 3: SYSTEM ANALYSIS AND CONCEPTUALIZATION

3.1 Maehae Social-ecological Context

3.1.1 Topography and Agro-ecosystem

The Maehae watershed is located 80 kilometers southwest of Chiang Mai city, and is one of the major forest-covered areas in northern Thailand and in the upper Chao Phraya River system in Thailand (Figure 3.1). Coordinates of the study area extend from 447862mE; 2073270mN to 454822mE; 2083010mN, with altitudes ranging from 960 to 1550 meters above sea level. The landscape of the Maehae area is mostly highland slopes, with an average of 30 degrees of slope. This highland area comprises about 3,288 hectares, with 70percent of the vegetation cover being pine mixed with evergreen and dry-dipterocarp forest.

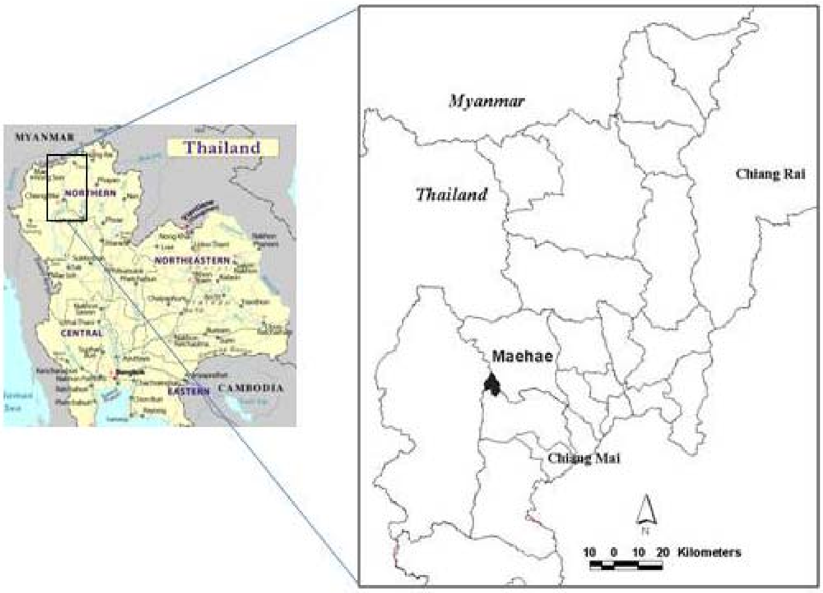


Figure 3.1: The study area, Maehae watershed

The Maehae climate is humid tropical and semi-temperate. The average maximum temperature is 31.75 Celsius in April, and the average minimum temperature is 11.78 Celsius in January. Average rainfall is 332.4 mm in August, and total rainfall is 870.52 mm per annum. Its high altitude and low average temperature provide a suitable environment for growing a number of crops that favor cold weather; some flowers and fruit trees; however, farmers in Maehae, mostly Karen and some Hmong, still grow rice, mainly paddy rice and some upland rice for household consumption.

3.1.2 Political Boundary and Settlement

There are fourteen villages (Karen and Hmong ethnic groups) and 570 households (264 Karen households, 206 Hmong household) and 2,941 inhabitants, scattered over three sub-districts (Tambon) in three districts (Amphoe), which are Tambon Maewin Amphoe Mae Wang, Tambon Mae Nachon Amphoe Mae Rim and Tambon Bor Kaew Amphoe Samoeng (Figure 3.2).

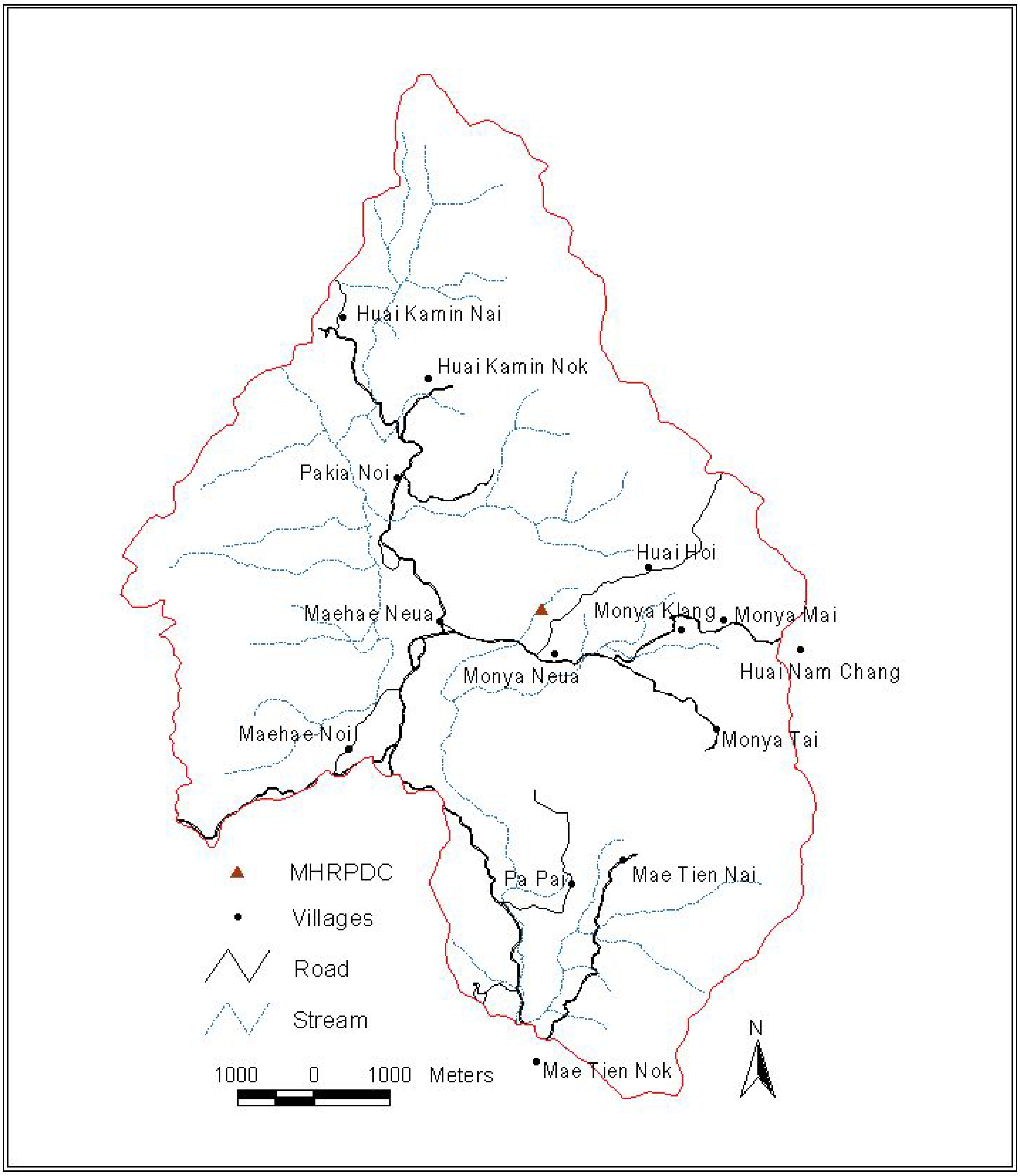


Figure 3.2: Villages, roads and streams in the Maehae Royal Project Development Center (MHRPDC)

3.1.3 Catchments and Water Sources

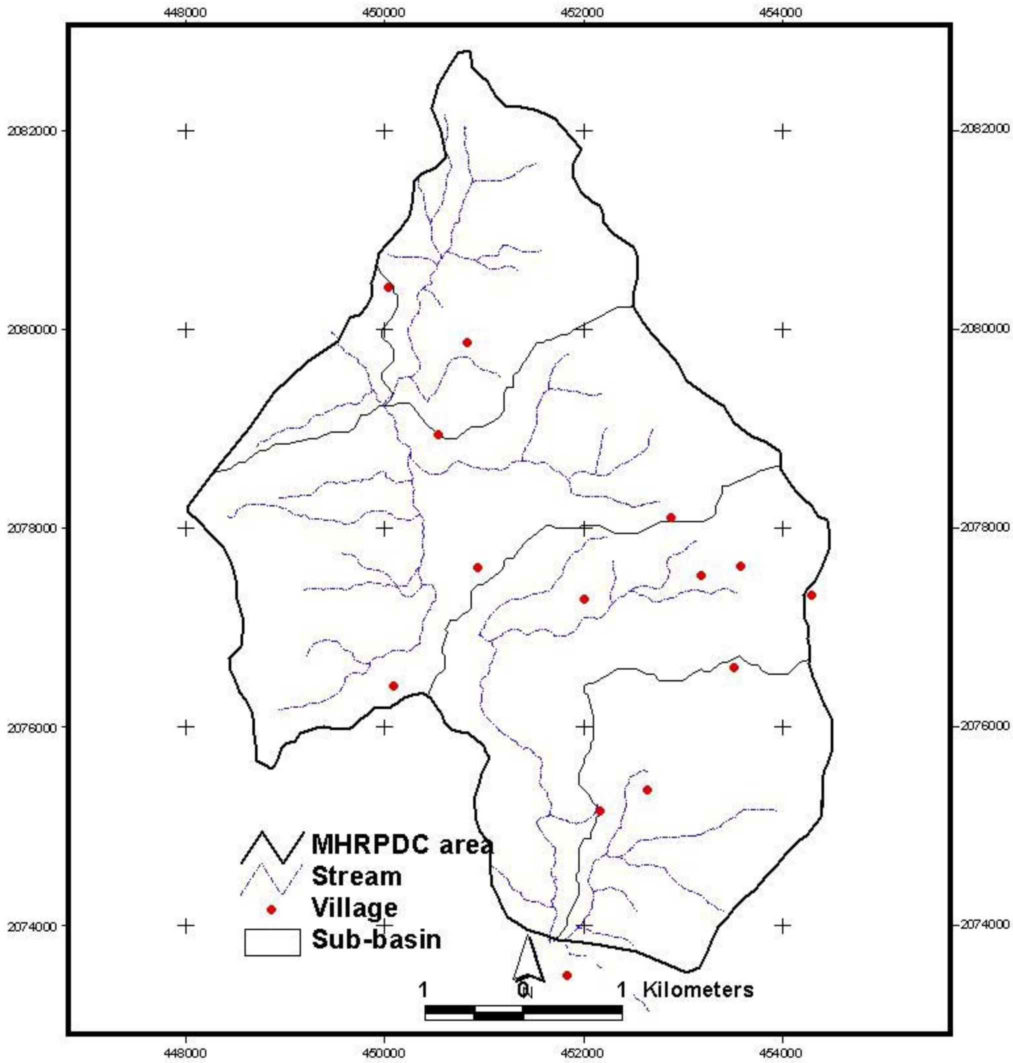


Figure 3.3: Sub-catchment and water sources in the Maehae.

The area can be divided into two sub-watersheds (Figure 3.3):

1.) Maehae sub-watershed. This covers the areas of Huai Hoi, Maehae Neua, Maehae Noi, Huai Kamin Nok and Huai Kamin Nai. There are two major tributaries in this sub-watershed which are:

- the upper, middle and lower Maehae sub-catchments where the creek starts in Maehae Noi and flows northward through the west of Maehae Neua, Pa Kia, Huai Kamin Nai and Huai Kamin Nok.
- Huai Kamin - Huai Hoi sub-catchment. Creeks in this area originate in the east and merge into the Maehae stream in the west.

2.) Mae Tien sub-watershed. This consists of two left and right sub-catchments. Its area covers the middle and southern parts of the study area. The villages in this sub-watershed are Monya Mai, Monya Klang, Monya Neua, Monya Tai, Pa Pai, Maetien Nai and Maetien Nok. The MHRPDC is also settled in this area.

There is only one reservoir in Maehae: Huai Hoi reservoir which is located in Huai Kamin - Huai Hoi sub-catchment, in the western part of Pakia Noi. It supplies water only to Huai Hoi valley, where villagers grow rice and vegetables through a pipe irrigation system. Most of the other irrigation systems take water from streams using small dams to raise the water level, and then divert the water through traditional irrigation canals, or through pipe systems using gravity or a water pump. The LDD has constructed four water tanks to store water from the upper part of the Maetien sub-watershed and irrigate crops in the nearby areas.

3.1.4 Watershed Classification

In 1985, the State launched an act to classify highland headwater areas in northern Thailand into sub-categories, according to the topographical characteristics relevant to hydrology. Factors used in this classification are landform, slope, elevation, geological structure, soil characteristic and forest condition. Therefore a water class possesses forest resource richness, altitude and certain land utilization, and this determines or allows certain land utilization practices, and it is used for land use planning (Figure 3.4). The watershed classes are:

- Class 1: This area is strictly reserved as headwater area, there are two sub-classes: 1A covers an area of 9,745.83 rai (1 ha = 6.25 rai) or 47.22 percent of the total area, and 1B covers an area of 642.79 rai.
- Class 2: This is also reserved as headwater area but can be used for some purposes such as mining and economic crops. It covers an area of 9,054.87 rai or 43.87percent of the total area.
- Class 3: This class covers an area of 1,196.43 rai or 5.80percent of the total area. This class can be used for crop cultivation.

3.1.5 Forest Type

Forest land within the MHRPDC are of responsibility consists of a reserve forest area and an economic forest area of 10,032.27 rai (48.61percent) and 10,196.08 rai (49.40percent) respectively. Almost half of the area is protected by forest law and is subject to remain forest area.

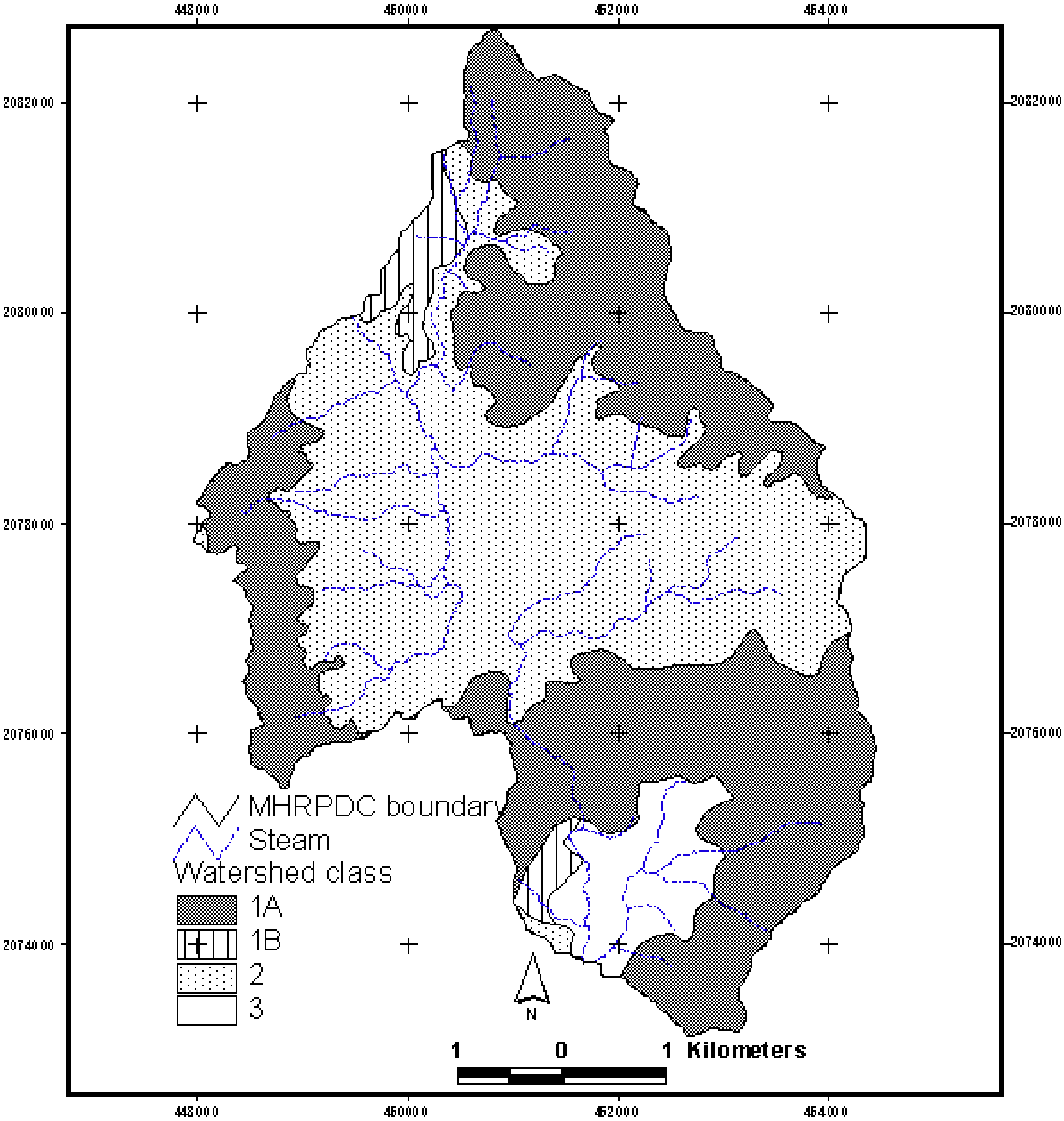


Figure 3.4: Watershed classes in the Maehae.

3.1.6 Land Utilization

In over two decades, the Maehae farmers have transformed their former swidden subsistence agriculture (upland rice, paddy rice and corn) into cultivation of high-value cash crops (such as lettuce, cabbage, parsley, zucchini and persimmon), as introduced by the Maehae Royal Project Development Center (MHRPDC) under the Royal Project Foundation (RPF), originally established in 1978 to supplement the national policy on opium eradication and to generate income for highland communities.

Land utilization types and areas in the Maehae in 2000 were classified from IKONOS satellite images by Ekasingh et al. (2000), and are shown in Table 3.1. Figure 3.5 illustrates the spatial distribution of different land use types within MHRPDC area.

Table 3.1 Land utilization types in Maehae: 2000.

Land Use Types	Area (rai)	Area %
Forest	14,314	69.9
Vegetables	477	2.3
Paddy rice	929	4.5
Field crops	304	1.5
Fallow/swidden land	2,914	14.2
Orchards	766	3.7
Plowed land	227	1.1
Bare land	22	0.1
Greenhouses	8	-
Water sources	14	0.1
Village	356	1.7
Road 477	224	1.1
Total	20,553	100

Source: Ekasingh et al. (2000)

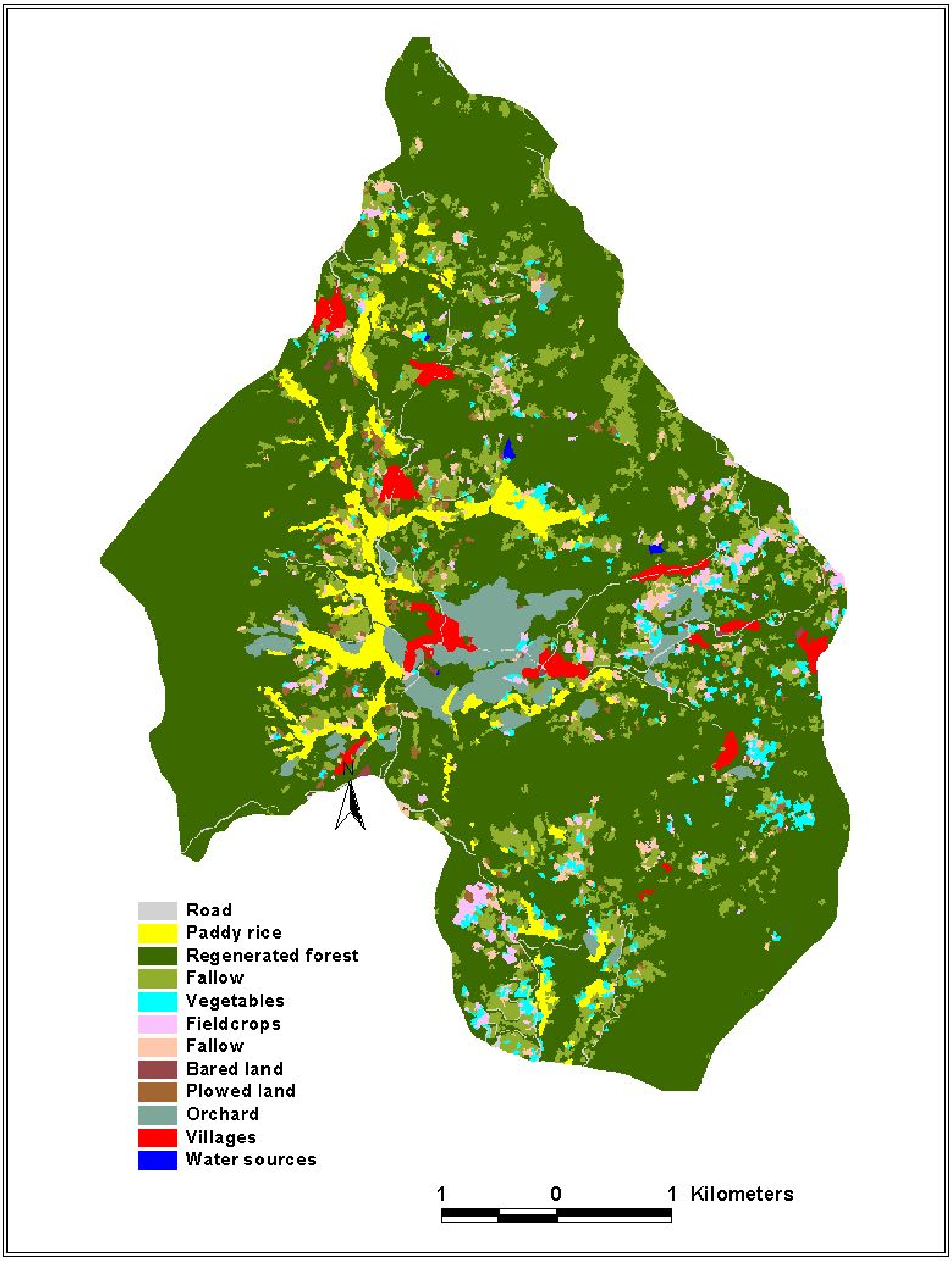


Figure 3.5: Land use types in Maehae: 2000.
Source: Ekasingh et al. (2000)

3.1.7 Historical Background and Community Settlement

The first settlement in Maehae community was founded around 100 years ago (1887); the Karen ethnic group moved in from a nearby area and settled in Maehae Neua, Pakia Noi and Huai Kamin, along valleys suitable for rice growing which is the traditional agriculture. In 1922, the Hmong community migrated into Monya Tai area; at that time Hmong people practiced swidden agriculture and they shifted cultivating areas from place to place. Later on, in 1937, more Hmong people moved into the area near Huai Hoi and the population increased rapidly (Leevisitpatana, 2003).

The traditional agricultural practices of the Karen are based on paddy rice, upland rice and other subsistence crops for household consumption. In this area, although stream water was abundant, Karen grew rice only once a year during the rainy season. The Hmong people, who naturally live at higher elevations, grew only upland rice and other subsistence crops. The Hmong also cultivated poppies to produce opium, which was the main income source or main product to exchange for other goods. Opium production became commercialized and the growing area rapidly spread. During 1972 (2437), the forest area decreased drastically due to shifting cultivation practices and opium growing. Bare land and grassland were commonly seen everywhere.

By that time, infrastructure had not been developed much; transportation between this highland communities and city was difficult thus there was little intervention from the Government. The first entry of the State sector was in early 1957 - to conduct a population census and issue Thai citizenship to the people and set up an official village and village leader, as with other lowland Thai political communities. Later on, infrastructure, education and health services began to be provided. During 1967 to 1970 there was military action in this area, in order to eradicate opium growing and substitute other cash crops for poppies. However, when the military initiative ended, the Maehae people returned to poppy growing again, because the substitute crops could not assure food security and a sufficient income.

In 1976, with regard to the spread of opium production, and for national security and highland resource conservation purposes, the Thai Government developed a new strategy; introducing commercial crops aimed at generating income and suppressing opium growing. This was when the MHRPDC was established, with alliances formed with other government sectors. The project wanted to generate sufficient income for the Maehae people, and two to three years later more people joined the project, which provided better transportation, and poppy growing declined. After 1984, crop products were increasingly commercialized and farmers gained more income and gradually stopped the traditional cropping practices. Some farmers allocated part of their farmland for growing fruit trees for long term investment, while farmers who held small areas of farmland could not grow fruit tree and so tended to intensify their cropping; resulting in a degradation of soil fertility. At this stage, new agricultural technologies were introduced to maximize crop production, one of which was the water ‘springer’; farmers who cultivated crops in far areas diverted water from streams to irrigate crops, thus, stream water use increased.

1988 saw the beginning of the commercial agriculture boom, as better transportation and communication developed, electricity reached the area and household needs shifted, with more TV sets, radios and other modern facilities. Vegetable growing became the main income source, and Maehae farmers intensified and expanded the area for growing vegetables. However, demand for land and water utilization also increased and contributed to land, forest and water resource degradation.

3.1.8 Agricultural Context, Transition and Changes.

The changes in agricultural systems can be divided into two stages: the first stage began around 1897, being a period of primary forests changing to traditional agriculture. The second stage was after 1976, when the community changed to a semi-commercial agricultural community. Concerning the effects on production, since 1976 the communities have adapted their livelihood to more commercialized agriculture, involving both vegetables and fruit trees. This has led to greater risk for the farmers, both in production and marketing. All-year-round income has contributed to a greater level of well-being and wealth of the farm households compared to the past; nevertheless, it has also created a disparity in income among the communities. With respect to the level of natural resources, there has been a downward trend on this, because land has been continuously cultivated.

Ekasingh et al. (2000) compared land utilization in the Maehae during 1986 (Figure 3.6) when the MHRPDC had just been established, to that in 2000 (Figure 3.7). They found a decrease in swidden agriculture, a practice that had scattered over the area in the past, while forest area had increased (Table 3.2). This meant that most of the previous fallow and swidden fields had been abandoned and regenerated to forest area.

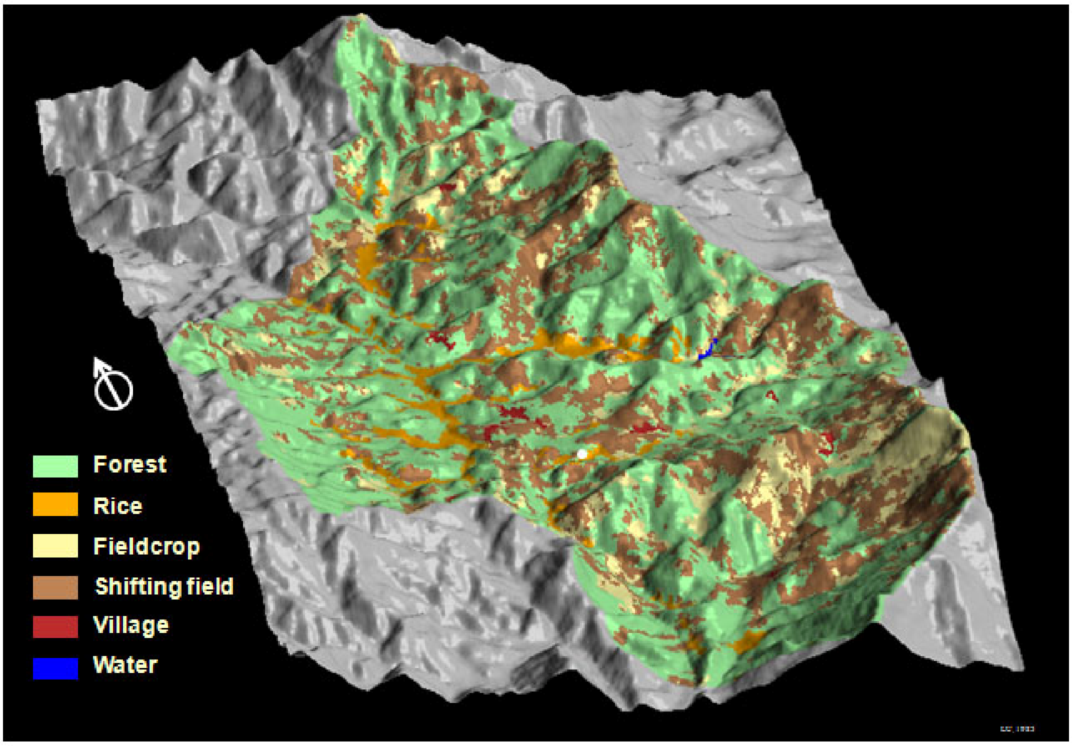


Figure 3.6: Land use classification in 1983.
Source: Ekasingh et al. (2000)

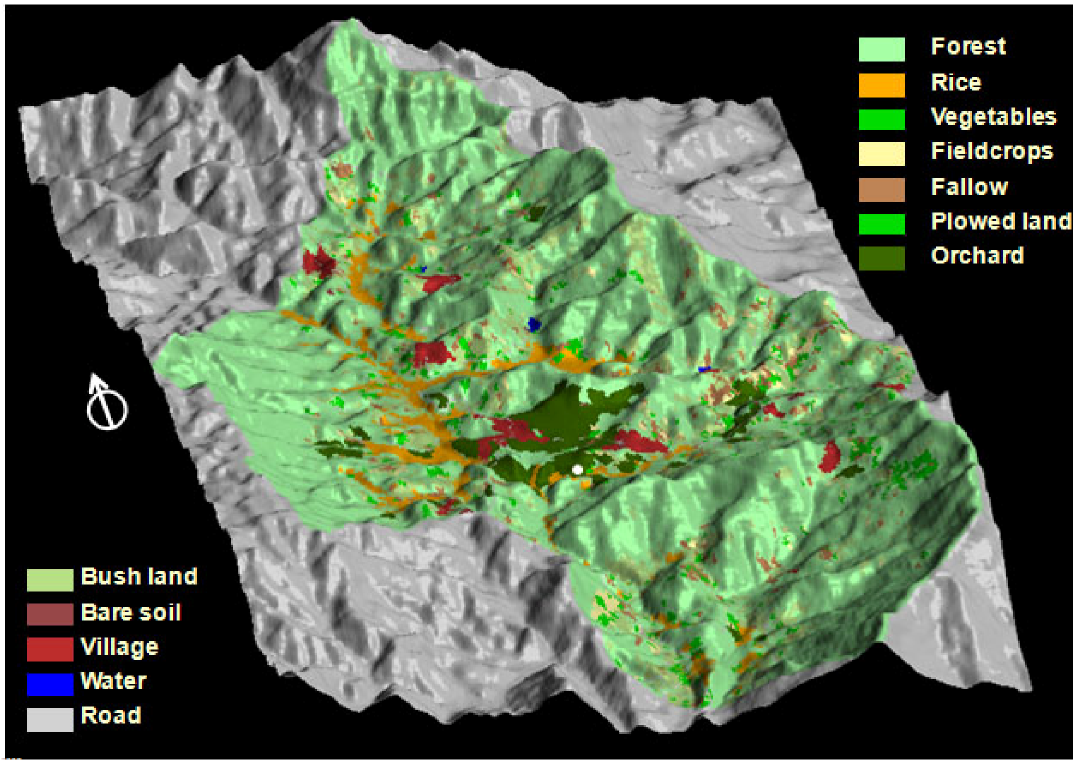


Figure 3.7: Land use classification in 2000.
Source: Ekasingh et al. (2000)

Table 3.2 Land use change in the Mahae during 1986 to 2000

Land Use Types	Area (rai)
Forest	1,997
Agricultural land	-114
Village	264
Road	221
Water bodies	5.1
Fallow/Swidden field	-2.356

Source: Ekasingh et al. (2000)

3.1.9 NRM Policy Development and Changes

The highland watershed areas in the north have been generally perceived as a fragile, vulnerable and susceptible national asset that should be subject to the protection and management of the Government, with highland dwellers and their agricultural activities in this area contributing to highland land and water resources degradation. The new Thai constitution in 1997 provided a range of new policies to empower stakeholders and local institutions to participate in managing their own local resources in a sustainable way. Under the Central Government's decentralization policy, legal power was transferred from central to local government, and tenure rights were given to communities involved in forest management. Despite its commitment to involve local people in managing the forests; however, there has been a lack of willingness on the part of the State to fully transfer power and control over forest management activities.

The Royal Project Foundation (RPF) was originally established to supplement national policies for opium eradication and to generate income for highland communities. The main objective of the RPF is to encourage integrated highland community development. The RPF engages a number of relevant government sectors to incorporate and carry out the tasks needed to achieve the objectives set; these agencies are the Land Development Department region number 6, the Chiang Mai Provincial Agricultural Office, the Irrigation Office 1 and the Northern Office of Accelerated Rural Development. Moreover, with regard to the Forest Law and Watershed Classification Act, the Royal Forestry Department (RFD) is also actively in charge of forest resource protection and headwater area conservation. Thus, the Maehae watershed falls into the category where common resources are located within the multiple political layers of resource management.

3.1.10 Recent Situation and Problem

As in other communities in this region, the heterogeneity of highland people arises from ethnicity, in which social and cultural institutions, goals and attitudes toward doing agriculture, household resource availability and views of their relationship toward the environment, are different (Ganjanapan, 1996). In addition, political intervention also significantly influences the diversity of co-dynamic processes between social and environmental systems, something that makes natural resource management situations more complex and uncertain. It is not easy to perceive and understand the effect of government agencies' roles and their interactions with social and environmental systems on the overall catchment system.

Thus, environmental components and key stakeholders, with their differing perceptions, should be analyzed to bring about a better understanding of how individuals behave and interact with the environment and how this may affect the dynamics of the system.

A multi-disciplinary research group at the Multiple Cropping Center, Chiang Mai University, Thailand conducted research comparing land use changes between two highland areas under the RPF's responsibility; it showed that the forest area in Maehae has been well maintained (Ekasingh et al., 2001). Further investigation was conducted to conceptualize the system and its functions. We collected secondary data from literature reviews, particularly reports from research works previously conducted in the study area on land use and land use change, and socio-economic analysis. The objective was to analyze land and forest resource use and management and its dynamics. We also conducted field surveys to collect primary data by interviewing local key informants, administrators and other agencies who have a role in agricultural development, and watershed resource protection and conservation, such as the head of the Maehae RPF development unit and the local forestry officer. The purpose of this was to analyze the farming system in relation to land and forest resource use and management.

Several government agency lines, such as the Royal Forestry Department (RFD), the Land Development Department (LDD), as well as the sub-district (*Tambon*) administration organization (TAO, a local authority) are responsible for forest protection and natural resource conservation in Maehae. The Maehae farmers face land ownership and utilization rights insecurity on their land, which is located within the state-protected area (reserved forest area; restricted National Watershed Classification areas). In 1992, pressure from forest conservation, through an expansion of the nearby national park areas (*Obkhan* National Park and *Doi Inthanon* National Park) instigated Maehae communities to form the watershed resources conservation network ('village network'). The establishment of this network was also encouraged by the local RFD officer. When set up, there were 24 members of the committee selected from twelve villages (now fifteen villages), including two representative from the local forest conservation unit. One of the committee's tasks is to manage and protect forest areas, as well as to protect the right to live and farm in the area. Rules and regulations for the forest resource accesses were initially set up and agreed upon by all members.

During the past decade, vegetable cultivation in Maehae has increased drastically, with a subsequent expansion of demand for water and land. This has brought about conflicts of interest between local farmers and government agencies responsible for Maehae watershed forest resources conservation, particularly the RFD. Although many key informants and village headmen have asserted that good management of forest resources by the village network has taken place, inconsistent information about land-forest use conflicts has been reported. In addition, forest clearing for agricultural land expansion has been observed. The LDD and RFD are the main government agencies working in the area and are responsible for natural resource conservation. The LDD promotes soil conservation practices to reduce soil erosion, while the RFD promotes forest resource rehabilitation. The conflict over land and water resource use within the community and also with government agencies in this area was observed during our most recent field visits, when some farmers had encroached upon and cultivated in the restricted forest area. The main issues resulting from the investigation are rules of access to land and forest resources, and the management of these resources under different, conflicting interests and situations.

3.2 System Conceptualization

In mid-2003, the research team examined the characteristics of natural resources management in Maehae watershed. The data was collected using secondary information from previous studies carried out by local research institutes. Semi-structured interviews with various local key informants and government agencies were also conducted to complement conceptualization of the Maehae system. The analysis process covered identifying principal stakeholders, and investigating their interests, characteristics and circumstances. The patterns and contexts of interaction, and potential conflict between stakeholders, were also captured. Pre-system analysis resulted in a list of key environmental components, key stakeholders and their important role in using and managing the forest, land, and water resources in the watershed area.

Based on the pre-analysis steps, key stakeholders and their roles were identified. The farmers face insecure ownership of their land because most of the cultivated land is within the national forest reserved boundary and under restricted watershed classes; hence, it is claimed as part of the state protected areas. The “tragedy of the commons” in Maehae is not negated within the communities that use resources directly and indirectly, rather it extends the effect to external beneficiaries, such as downstream and urban communities. This second dilemma thus induces external intervention to re-design the rule of forest resource governance, for instance forest-reserve law. However, the difficulty in enforcing and monitoring the forest exploitation provides the flaw for local users to be able to over extract this resource.

The RPF, Land Development Department officer (LDD), and Royal Forestry Department officer (RFD) are key government agencies working in the area. The RPF Development Center has actively introduced and supported cash crop and fruit cultivation in order to increase farmers’ income. LDD and RFD are responsible for natural resource conservation; the LDD promotes soil conservation practices to reduce soil erosion. Thus, a trade-off situation occurs where farmer cultivate crops on sloping farmland that is prone to erosion. The RFD promotes forest resource rehabilitation through collaboration with local people, though occasionally, conflicts over resources use have occurred. For example, there were some farmers who encroached upon and cultivated in a restricted forest area, and disagreed on water sharing.

This pre-perception on environmental components, stakeholders, their actions and associations, issues that influence the Maehae system dynamics, was transformed into the preliminary design of the ‘world’ that represented the Maehae watershed, a system consisting of three major components, corresponding to the stakeholders, their ecological environment and the local institutions. Stakeholders share and intervene in common resources with different objectives and perceptions, while local institutions are formal and informal groups or organizations representing stakeholders who share similar interests. Figure 3.8 illustrates a simplified conceptualization of the Maehae watershed system. The solid arrow line represents either a one- or two-way association between stakeholders, while the dashed line and its gradient show the level of perception and understanding toward an interested context.

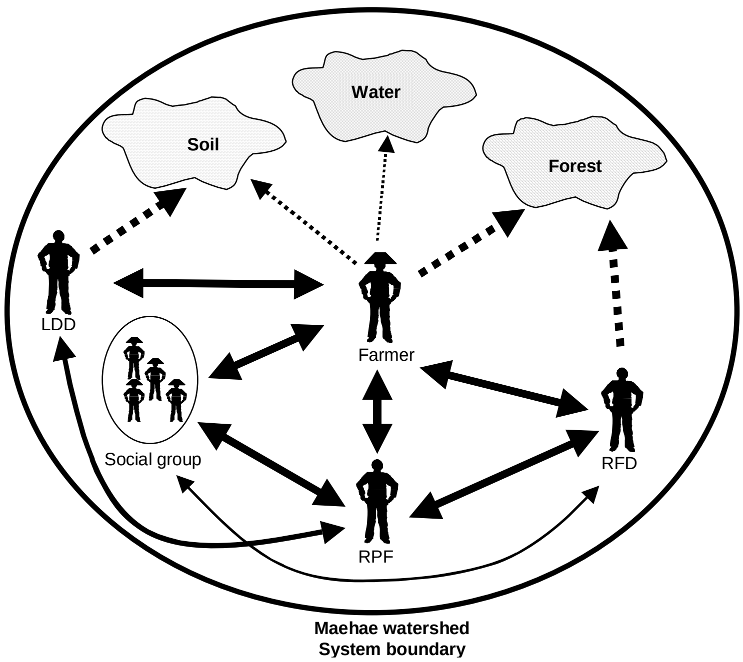


Figure 3.8: Conceptualization of the Maehae watershed

CHAPTER 4: ROLE-PLAYING GAMES AND INSTITUTIONAL ENGAGEMENT FOR BETTER UNDERSTANDING THE SYSTEM; FACILITATING COLLECTIVE LEARNING AMONG STAKEHOLDERS

The previous investigation on the Maehae watershed system and the conceptualization of stakeholders' resource perceptions and relationships led to the identification of the main issue: access rules to the land and forest in conflict situations.

The companion modelling approach was used in this research because it involves a group of people who share common resources but have different interests. The objective is to elaborate a common understanding of the dynamics at stake. In general, people start with an identified problem, but the first phases may reveal that this is not the actual problem, or that this problem is associated with another problem. This companion modelling approach usually has to accompany the process with its continuous changes and surprises. Thus, it is difficult to precisely plan the actions in the field beforehand.

In this study, the first focus was on land and forest resource management, as identified by the previous investigation. Role-playing game (RPG) sessions were designed and implemented to better understand stakeholders' roles and actions in managing the resources under conflict of interests. Then, the focus of interest issue turned to water management due to the severe drought which occurred afterward. The long term vision on the future and resource management problem was assessed, and this resulted in the identification of the common concern on water deficit and water use conflict for irrigation. Thereafter, a RPG was implemented with local farmers to explore local water use and management, and to observe individual and collective response to water scarcity. The land, forest and water management issues were related to each other, and it was suggested that this problem should be taken into account at the institutional level and beyond the individual level.

This chapter describes the process and presents the land-forest RPG, the visioning exercise, the RPG on water management, and finally the role and functions of local people.

4.1 RPG on Land-forest Management

An RPG was designed with the following objectives:

a.) to verify the pre-conceptualization of stakeholders practices, roles, interactions and perception of each other. More precisely, the objective was to understand the behavior of farmers concerning agricultural land and forest management, as well as their interactions with the local forester with whom a conflict of interest exists

b.) to facilitate the exchanges of points of view, and initiate collective learning of stakeholders on system structures and processes. Furthermore, this activity was supposed to lead to trust building between stakeholders and researchers, which is important when dealing with a sensitive issue like forest management, which is regulated by law and linked to security and rights to own and access the land.

Toward the end of 2003, the first game was designed as a simplified version of the previous complex conceptualized model. Simplifications were made regarding the heterogeneity of the landscape and diversity of stakeholder's situations. Some rules and constraints concerning access and management of the land were flexibly defined but most social rules were left open to the player. The game pre-testing was conducted with graduate students who had a background in agricultural economics and agronomy, to validate some rules, parameters and materials used in the game before conducting it with stakeholders in the field. This game was played two times.

4.1.1 First Session of the Land-forest Management RPG

4.1.1.1 Settings

The first land-forest RPG session was designed and played by twelve local farmers from both the Hmong and Karen communities. The players were chosen using household data that included name and age of the household members and economic status within the village, collected from the village-headman of each village. After that, the research assistant, a local Maehae inhabitant, visited them and invited them to take part. We planned for and expected an equal number of players from the two ethnic groups in each farmer category, but some were not able to come due to urgent activities, thus there were three new players recruited on the game session day. Ten of them represented three different types of farmer corresponding to different economic statuses, these being: rich (type A), medium–income (type B), and poor farmers (type C). Among these farmer types, they were each given a different amount of money for investment and cost of living per round of the game (initial money and cost of living: A = 10,000, B = 5,000 and C = 3,500). There were three players of type A, five players of type B and two players of type C, and they were assigned to perform the role of farmers who cultivate farmland in a watershed area. Each farmer player was given a different farmland size. The players could select and cultivate high value cash crops introduced by the Royal Project Foundation (RPF) and could convert forest area to new farm plots in order to expand their farm size and cultivate more crops.

Two players were added just before the game; who are well educated and had frequent access to updated information, and they were assigned to perform the roles of Royal Forestry Department officer (RFD) and the Land Development Department officer (LDD). The reason for having local people perform these roles was to free-up the other players to perform their given roles, particularly for their first role-playing game. The roles of the RFD and LDD were explained to those players performing these tasks. The RFD player was assigned the task to monitor and protect the forest resource. He was responsible for maintaining the forest area above 40 percent of the total area threshold, which was the initial forest area at the beginning of the game. If the farmer player created one new farm plot, this would reduce the forest area by one percent, and thus, he had the right to withdraw any farm plot newly created by the farmers in the forest. Likewise, the LDD player was assigned the task to promote soil conservation practices in the vulnerable area, to reduce soil erosion. The amount of erosion varied by the combination of slope, crop type and rainfall conditions. In general, no erosion occurred on flat slopes, fruit orchards and fallowed land; growing other crop types on low gradient slopes and on other steeper slopes would cause two and three units of soil erosion respectively. However, managing the soil conservation practice would make crop production of that plot decline by 25 percent.

Knowledge on the relationship between land gradient, cultivated crops and erosion vulnerability was discussed with and confirmed among the players. Rice is always grown on flat land, while vegetables and flowers are mostly grown on flat and moderate slopes; only a few are grown on steep slopes. Fruit orchards can be grown on any slope type except flat land, while upland rice is mostly grown on moderate and steep gradient land; with non-flat land can be left fallow. Communication among players was allowed during the game session.

Name cards labeled with the player's name and status symbol were distributed and tagged to help communication between game facilitators and players. One of the research team acted as the moderator of the game, assisted by four facilitators. The details of the RPG are provided in Table 4.1.

Table 4.1: The players and environment setting of the first land-forest RPG session

Players and Environment	Detail
Player	12 farmer-players - Type A, rich (2 Hmongs, 1 Karens) - Type B, medium (3 Hmongs, 2 Karens) - Type C, poor (2 Hmongs)
Forester and LDD officer	Two local, young, well-educated farmers.
Crop choices	- paddy rice - upland rice - vegetables/flowers - fruit orchard - upland rice - fallow
Rain	Randomly selected: dry, medium, good
Crop price	Randomly selected: low, medium, high
Game rules	- Farmers freely allocate crops in their given farm-plots. - Farmers are allowed to create new farm-plots, only one plot for each game step. - The Forester should protect and maintain a forest area >= 40percent. - The LDD player should suppress soil erosion <= 20 units
Communication	- Open communication and negotiation among players.
Indicator	- Farmer's cash income - forest area - soil erosion

The 3-D block model was used to represent a simplified typical highland watershed, with various slope classes. The model was created to represent three categories of landscapes, corresponding to foothills, mid-hills and top-hill areas (Figure 4.1). The game facilitator showed and explained the characteristics of the block model to the players, but did not explicitly point on the board to show the player where the flat, low, moderate and steep sloping areas were. This was done to assess the ability of each player to relate the 3D board related to the highland landscape.

Figure 4.1: The 3D-board, farm and plots locations used in the land-forest RPG.

At the initial stage of the game, each farmer received a different number of cultivated plots, located on varying slopes (Table 4.2). The number of given plots and their slopes and location corresponded to the reality. For example, rich and middle-income status farmers possessed some paddy land, which was not made available for the poor farmers. According to their status, each farmer received a different amount of initial cash to invest in crop cultivation, according to their given status. There were four types of crops from which a farmer could choose to cultivate on their plots: paddy land, vegetables and flowers, fruit orchards and upland rice. Investment costs for the different crops were post on the board.

Table 4.2: Number of farm-plots and slopes assigned for each farmer player

Farmer/ Farm plot	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
A1	F	F	F	L	L	L	L	L	M	M
A2	F	F	F	L	L	L	M	M	S	
A3	F	F	L	L	L	L	M	S		
B1	L	M	M	M	S	S				
B2	L	M	M	M	M	S				
B3	L	L	M	S	S					
B4	L	L	M	M	S					
B5	L	L	M	S						
C1	M	S								
C2	M	S								

Note: F = flat, L = low, M = moderate, S = Steep

4.1.1.2 Steps of the Game

Each step in the game represented a one year period. The individual farmer could freely allocate different crops to the given land, and each farmer was allowed to open new plots in order to increase the crop production area. The RFD player had the right to withdraw any plot opened during the previous time step, but only two plots at each time step. This corresponded to the actual difficulty in monitoring the forest area. Coordination and negotiation between farmers and RFD was not scheduled in the game, but was allowed if it emerged during the game.

During the game, the LDD officer monitored the plots prone to erosion and tried to convince the plot owner to accept soil conservation practices. If the owner agreed to do so, there would be a trade-off on the 25percent crop production lost on that plot.

At the end of each time step, the random climate condition was announced. This affected crop production and soil erosion. Then, the crop allocations on the 3-D block model were collected and used to calculate farmers' income balance. The farmers whose income balance was less than the amount needed for investment in the next game step were allowed to continue as if they were able to access credit sources. Lastly, the moderator aggregated and announced the amount of erosion and remaining forest area to all players. The aim of this was to encourage the RFD and the LDD players to actively play their roles for the next gaming session. During the game process, facilitators and the moderator observed some of the interesting actions and interactions among the players.

4.1.1.3 De-briefing after the Game

Four time steps were conducted during the morning session. Players and game facilitators had lunch together, allowing informal conversation. According to the comments of the players there were then some changes introduced for the afternoon session, these being: farmers had no limitation in opening new plots, while the RFD was allowed to withdraw an unlimited number of plots.

Right after the game, we conducted an informal group discussion. All players felt familiar with the game; more comfortable to talk and express their ideas. Most of them could recognize and relate the 3D model to their real landscape. The type of crops and investment costs were similar to reality, but the product prices needed to fluctuate every year. They also suggested that the probability of suffering a dry year was much higher than a wet year. This led to some rule adjustments being applied for the second game session.

4.1.1.4 Lessons from the first RPG and the Interviews

It was observed that two poor farmers decided to open new plots at time steps 1 and 2. This significantly decreased forest area, thus encouraging RFD to play the forest protection role actively. During the next step, the RFD took the newly opened plots away from the two poor farmers, and as a result, communication and negotiation between the RFD and poor farmers emerged. The result was that the RFD took only one new plot from each poor farmer and allowed the others to remain until the end of the game.

The LDD player tried to convince farmers to adopt soil conservation practices after two time steps, as he was concerned by the increased amount of soil erosion announced on the public board. He went to the 3D block model and communicated with the farmers, trying to gather information from farmers of the same ethnicity. This was clarified during the follow-up interviews conducted after finishing the game: in real life, the farmers rarely communicate and negotiate across communities and even less so between two ethnic groups.

A collective behavior when trying to compromise with the RFD and LDD was revealed. Forest area and soil erosion increased during the initial steps and then declined to a steady state towards the end of the game (Figure 4.2). This was in contradiction to the pre-perception and the results of the pre-test game conducted with the students. It was expected that the one who played the role of the poor farmer would encroach on the forest area to claim more land to increase production, in order to fulfill household needs.

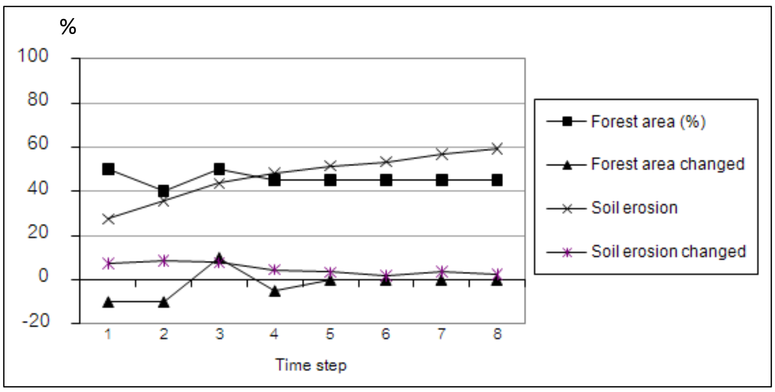


Figure 4.2: Forest area and soil erosion changes during the first RPG

The interviews confirmed that fifteen villages had been coordinating with the forest conservation network for more than ten years in order to manage and protect forest areas. Rules and regulations on forest resource access were set up and agreed upon for all members, in order to lower the degree of forest law enforcement, since most of the agricultural area falls into forest reserve area. This networking was the initiative of communities, with the close support of the local RFD officer.

Furthermore, the game revealed that most of the players do not directly know the role of the LDD, but have experienced some of the soil conservation practices implemented through RPF. However, collective decision-making on suppressing soil erosion emerged during the game, and during the discussion right after the game, some of the players indicated that the increase in soil erosion had motivated them to cooperate with the LDD. Both sets of players acknowledged the knowledge they had gained about soil conservation from the LDD.

4.1.2 The Second Land-forest Game Session

4.1.2.1 Settings

The second game session was conducted in early 2004, one month after the first game session. As with the first session, the aim of this session was to clarify the understanding on how farmers adapt when they face limited land resources and forest protection policies. Moreover, this session tried to reproduce the history of changes in agriculture. There were eight farmer players, four of whom had participated in the first game, and the rest came from different villages.

At this time, the local forest officer was invited to perform the role corresponding to his own duty. One player was assigned to perform the LDD role, because the real LDD agent rarely contacted or communicated directly with the farmers. Some rules were adjusted according to the objectives and based upon comments from the players in the first game session. These rule adjustments were:

- Ratio of climatic conditions: good : normal : drought was 1:1:3;
- There were no high value cash crops and fruit orchards during time steps 1 and 2 (reproducing the actual history of agriculture in this watershed);
- Crop product prices were ranked good, medium and low, and were randomly chosen. This would affect the household’s cash income.
- An increased cost of living.

These adjustments were designed in to put more constraints and pressure on the player when trying to achieve household well-being due to climate conditions and price fluctuations. This was expected to induce self-interest among the behavior of the players.

Group discussion was conducted after the session ended in the afternoon, to obtain collective ideas on specific issues observed during the game session. Individual interviews were conducted in the evening and the day after to follow up on decisions made and behavior observed during the game.

4.1.2.2 Lessons from the Second RPG

During the game, poor farmer players tried to get more land for cultivation in time steps 1, 2 and 3. When the forest area declined to 40percent, which was the alarm level for the RFD (the task given to the RFD was described to all the players before the start of the game), the information spread within the group and instantly the players regulated their actions without any forced action required from the RFD player. This described the players' point of view with regard to the forest resource situation and management. The regulations were so embedded in the minds of the players that the regulator did not need to force them to take action. The performance on soil erosion showed similar coordination, which was closely consistent with the first game (Figure 4.3).

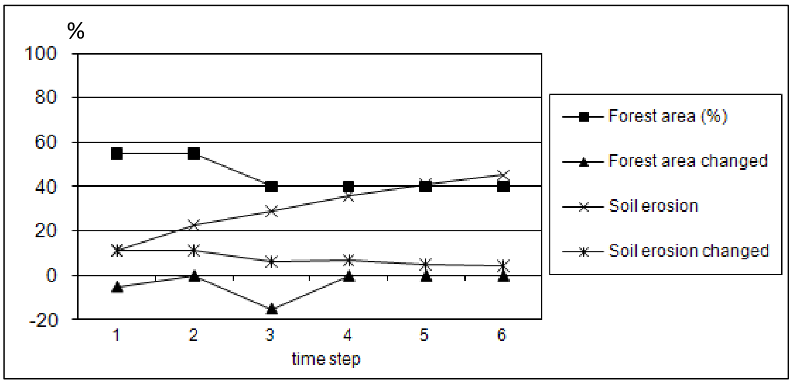


Figure 4.3: Forest area and soil erosion changes during the second role-play game session

During the interview, most of players expressed the view that the first two time steps were similar to the situation as it had been in the past. Before the RPF was established in 1978, agricultural productivity was low. Thus, people needed more land to produce crops and generate an income. The discussion after the game supported this historical scene. Furthermore, the younger more educated generations now have more employment opportunities, so the dependency of the household income on agriculture has gradually decreased.

4.1.3 The Results and Findings from the Land-forest RPGs

These two RPG sessions revealed that the players who had little farmland and could not grow enough crops tended to expand their farmland by creating new farm plots. The opposed roles of farmers and forester players provoked individual reflection and interaction among them. The local RFD player did not withdraw the new farm plot unless he realized that the forest area was going too far below 40 percent, and then he negotiated with the farmer players who had opened new farm plots. During the game, farmers collectively negotiated and compromised with the RFD to allow poor farmers to keep some of the new farm plots, as well as maintain the forested area close to the given threshold. We found that the games facilitated collective learning about the change in cropping patterns from subsistence agriculture to high-value cash cropping, a change that has contributed to farmland expansion. They recognized that individual small-scale farm expansion collectively alters the whole watershed property that is under the responsibility of the local RFD officer. Group discussion after the games provided a better understanding of the role of stakeholders in using and managing land and forest resource. The player interviews confirmed these outcomes and revealed the reasons for decisions made and actions carried out during the game. In addition, the game process established trust between the researchers and local people, and thereafter, this helped us to carry on further investigations to clarify information that had previously been vague; other people who heard about the research team from friends and neighbors who participated in the RPG felt comfortable talking and providing information to the research team. Table 4.3 summarizes the results digested from the land-forest RPG sessions.

Table 4.3: Findings, output and outcomes from the land-forest RPGs

Finding/Output/Outcome	Detail/Evidence
a.) Verification and modification of the system conceptualization (farming practices, stakeholders, roles, interactions and perception toward others, and resource management and problem concerned)	- crop choice and allocation. - the farmer objective was to grow rice for consumption and grow vegetables for cash income. - the forester had a close relationship with local people, whereas the DLD officer did not. - the farmers were concerned about both doing farm and forest conservation..
b.) Behavior of the farmers toward agricultural land and forest management, as well as their interactions with the local forester with whom a conflict of interest existed,	- small land-holder may have created a new plot. - local farmers knew the role of the forester and tried to compromise the conflicting objective by collectively maintaining forest areas close to the foresters satisfaction level.
c.) Exchanging point of view; collective learning of stakeholders on system and dynamic processes.	- players understood the relationship between cropping pattern changes and land-forest resource dynamics. - players could see how individual action affected other individuals and the whole system (for example, creating a new farm-plot affected the goals and actions of the Forester).
d.) Trust	- The players understood the role and objectives of the researchers and disseminated information to other villagers.

Information and lessons learned from the RPG and follow-up interviews were analyzed, together with the additional key informant interviews, and then compared with the pre-conceptualization diagram. The conceptualization diagram in Figure 4.4 illustrates the new outlook toward the Maehae watershed system. Major changes include the perceptions of stakeholders toward resources, associations made and the flow of information among stakeholders, other additional stakeholders and external factors, those that may influence system changes in the future. All perceptions and degrees of association which varied from the pre-perception are represented using gray lines.

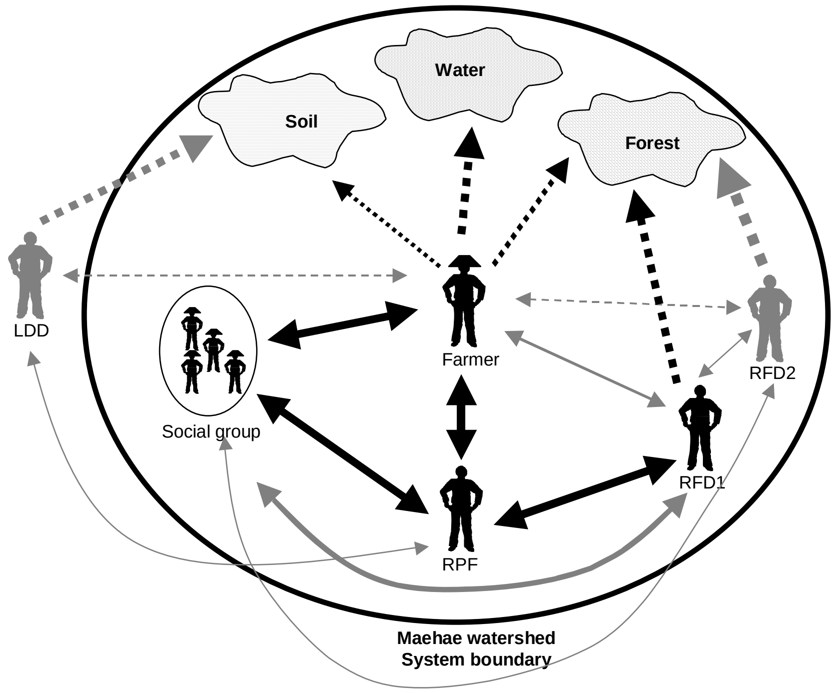


Figure 4.4: Revised conceptualization diagram of the Maehae watershed system. The solid arrow line represents the association between stakeholders; the dashed line and its size shows the level of perception and understanding with regard to resources.

After the games we can consider that LDD officer as a stakeholder outside the system boundary. In reality, the regional LDD proposes plans and budgets to restrain soil erosion in the highland area. This is then implemented and promoted through collaboration with the RPF staff. Furthermore, the soil erosion that occurs in Maehae is relatively little when compared to other areas under the responsibility of the RPF (Ekasingh, 2003). Field observation and the interviews confirm that farmers are concerned about soil fertility, and prepare the cultivated-bed-plots against slopes, to prevent a “good soil lost” situation.

Most of the players are directly familiar with the RPF and local RFD officers, the so-called RFD1 in Figure 4.4 (forester in the RPG). The village network is a social group that strongly influences local forest management among communities in Maehae (as emerged during the RPG). Therefore, from the players’ point of view, forest degradation is not a problem for Maehae community, because it is locally managed.

The discussions revealed the existence of ‘RFD2’ who is a new stakeholder representing forest officer from the forest protection division. He arrests those who act illegally against the national forest reserve law; he is stricter than the RFD1. The RFD2 communicates indirectly with farmers but through their social group. The forest protection division is now proposing that the national park expand to cover Maehae watershed area, and this will likely lead to more forest law enforcement and restrictions.

The lessons from the RPG and field investigation for the MAS model design have led to the following choices being developed. There are three types of farmer agents, one RFD agent and a space which is composed of farmland and forestland. The important elements and agent behavior are as follows:

- Farmer agents select and cultivate crop types recommended by the RPF
- Concurrent cultivated areas are limited by the crop investment cost and farmer's cash; the maximum is five farm plots
- The farmer who holds small farm acreage may encroach upon forestland in order to expand farm area, and
- The new farm plots might be observed and withdrawn by the RFD agent. A compromise can be made depending on the total forest area (the number of new farm plots in the model).

4.2 Re-analysis and Evolution of the Problem at Stake

After the land-forest role-playing game had been completed, we stayed in contact with the villagers and conducted ground surveys for spatial map preparation (land use maps, reserve forest area maps and watershed classification maps, plus aerial photographs). In early 2004, a severe drought occurred in Maehae. Farmers abandoned some farm plot where water was insufficient, and a number of new farm plots were observed, mostly near creeks or water sources, especially headwater areas at higher elevations; giving better access to water. We assumed that this environmental change was a major factor influencing farmland and water management adaptation, in addition to increase farm size. Key informants (village headmen, the village committee and other social leaders) in different villages were interviewed using semi-structured interviews to understand their mental representation of dynamic changes and interdependencies of forest, land and water resources. These findings reaffirmed the researchers' understanding of the linkages between farm size, water deficit and new farmland expansion onto forest land. At the end of each interview, interviewees were asked to express their long-term vision for the community's agricultural practices and changes in land, forest and water resources. Due to the recent drought, water scarcity was most often identified as a long-term problem. Further investigation using field observation, semi-structured interviews and focus group discussions was conducted to acquire information about water uses and management practice, as well as problems that had occurred in the past.

Table 4.4: Number of the Maehae people interviewed for water use and scenario visioning during April to June 2004, and January to April 2005

	Karen	Hmong
Key informants	7	4
Villagers	15	11

The Maehae area is comprised of three sub-catchments where water availability is different. Among the Maehae farmers, the "first-come, first-served" principle is part of the local regulatory framework: the one who first accesses water in the upper stream area has priority over those in the lower part. This also implies the privileges of those farmers who can establish a water pipe system to divert stream water to their farmland, or farmers who own farmland near upper streams. This rule applies among farmers who access water from the same creek and within an observable distance. Therefore, a farmer who seeks better farmland and water access might encroach upon forest areas at a far distance and at a higher altitude, or at different creeks. The increase in cash crop cultivation during recent years as well as the recent drought has widened the water availability gap between Maehae farmers, and this has brought about conflict for land and water use among farmers. The early field investigations provided for a description of water use and management in the Maehae on an individual basis. We therefore decided to conduct another RPG to represent the dynamic of farmers' group interactions on water management. The objective was to test the understanding and promote discussions among farmers on collective water management.

4.3 RPG on Water Management

An RPG dealing with water use and management for vegetables grown by farmers in upstream and downstream areas was conducted in order to check and clarify the existing knowledge on local water use and management practice, and to facilitate collective water management discussions under water scarcity conditions. We used household survey data collected from the village headmen of all the villages to select players for the game. We categorized players into three types using farm size (large, medium and small), and within each type we selected four players (an equal number from Hmong and Karen villages), who owned farmland with good, medium and poor water availability. Twelve players were chosen and invited to take part in the RPG, but the one representing the large farm did not appear on the session day. The eleven participants represented three upstream farmers, four midstream farmers and four downstream farmers. Table 4.5 describes the detail of the water management game design.

The two-dimensional board used for the game (Figure 4.5) was visually divided into three sections, representing players' farmlands with a different number of farm plots, situated in upstream (A), midstream (B) and downstream (C) areas. On the top of each area, there was a symbol of the water pond that farmers usually build to store water in higher altitude areas, and then use to divert water to irrigate the farmland.

Table 4.5: The players and environment setting of the water management RPG

Players and Environment	Detail
Player	11 farmer-players - three upstream farmers - four mid-stream farmers - four downstream farmers
Crop choices	- Lettuce - Cabbage - Red cabbage - Chinese cabbage
Rain	Randomly selected: dry, medium and good
Crop price	Randomly selected: low, medium and high
Game rules	- Farmer on the upstream play first (“first-come, first-served rule). - Farmers freely allocate crops in the given farm-plots. - Farmer may invest to establish irrigation pipes, to get a better priority on water access. The problem is that this contradicts the first-come first-serve rule.
Indicators	- Farmer’s cash income - Water balance

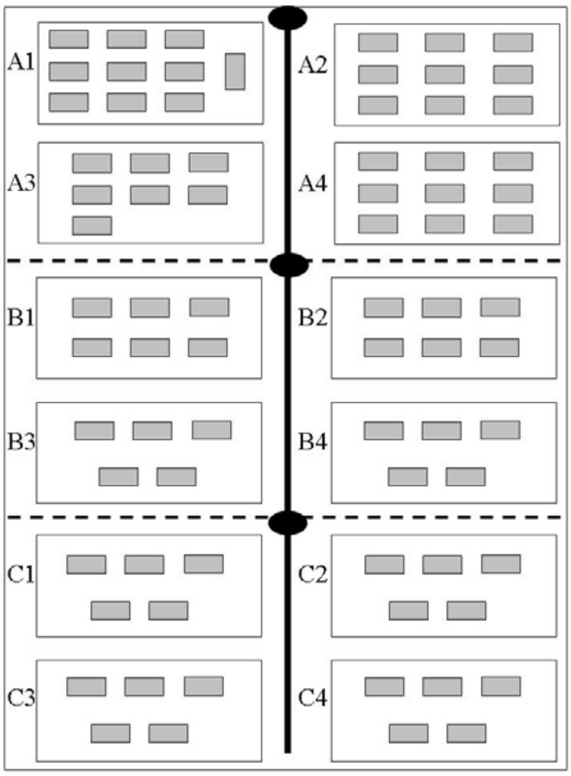


Figure 4.5: The two dimensional board used in the RPG. Each player has a different number of farm-plots and farm locations (a = upstream, b= mid-stream, c = downstream).

Before starting the game, players examined the game board to recognize each farm, its location and the number of plots. The moderator explained the tasks and rules to the players, but did not mention the possible utilization of the pond. The rules, environment and steps applied to each round of the game were:

- Players in the upstream area played first, midstream and downstream players played one after the other respectively.
- Anonymously, each player freely decided the number of cultivated plots and vegetable type.
- A player randomly drew the rainfall conditions and vegetable price.
- The available water was supplied in order to farm plots in upstream, mid-stream, and downstream areas.
- The plot without a water supply could not harvest.
- The game moderator then showed the playing board to all the players to reveal the number of cultivated plots and crop allocations of all the players.
- Players harvested and sold their products at the market desk and received an amount of money. The amount was calculated based on the crop, the quantity of water, the random rainfall conditions and the price.
- Players were able to establish an irrigation system with a given of cost, which would affect the water accessing sequence.

In the first round, some players whose farmlands were allocated in the mid-stream and downstream areas failed to harvest due to water shortages caused by upstream players who decided to cultivate many plots. After the first round, a player asked for the use of a water pond, thus the moderator announced that all could access water incurring a fixed cost for a pipe system. Thus, at the start of the second round, some players requested the construction of a pipe system to bring water to their plots. This resulted in changing the water access order. For example, in each farm area, the player who had a water pipe had the right to access and share the water equally with those others who had a pipe, before sharing with the other players who had no pipe system.

The result was similar to the first round. This prompted players to pause the game and to request negotiations among themselves to find a solution. Before the beginning of the third round, the players agreed to reduce the cultivated area (the number of farm plots), but there was no proposition for the number of plots to be farmed. After the third round, some players still had water shortages, thus the players requested another meeting. The proposed rule as a result of the discussions was that each player could cultivate up to three plots. This rule worked well for the third and fourth rounds. The result of the game session in the morning is shown in Figure 4.6.

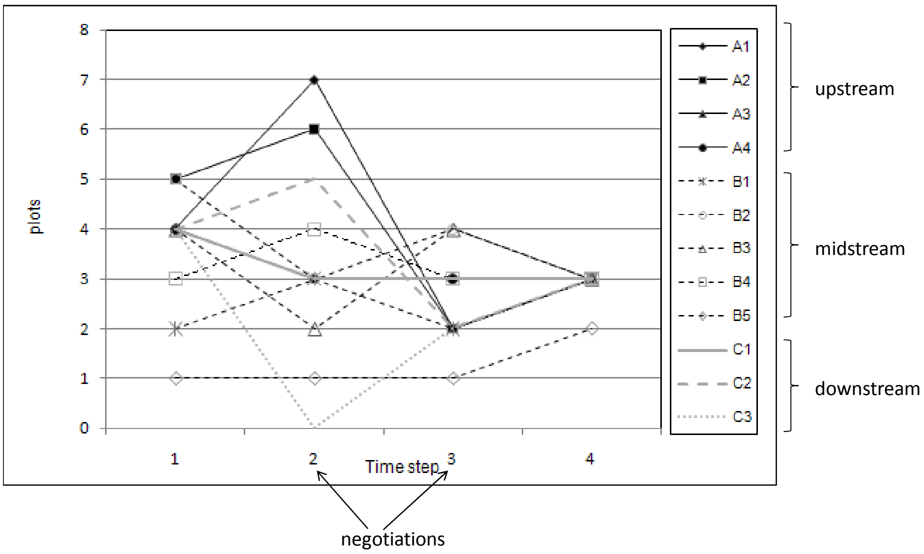


Figure 4.6: Number of cultivated plots for the first game session; round 1 to 4, in the morning. The negotiations occurred at the time step #2 and #3.

In the afternoon session, players in the upstream swapped their roles with the downstream players to observe their farm and water management practices. More market demand for all crop products, that made the crop price reasonable good and stable was introduced into the game. Unfortunately, three players were absent, to go back to their vegetable fields. During the last three rounds, it was found that the players tended to disregard the agreed-upon rule, and hence the number of cultivated plots increased drastically, and crop failures occurred (Figure 4.7).

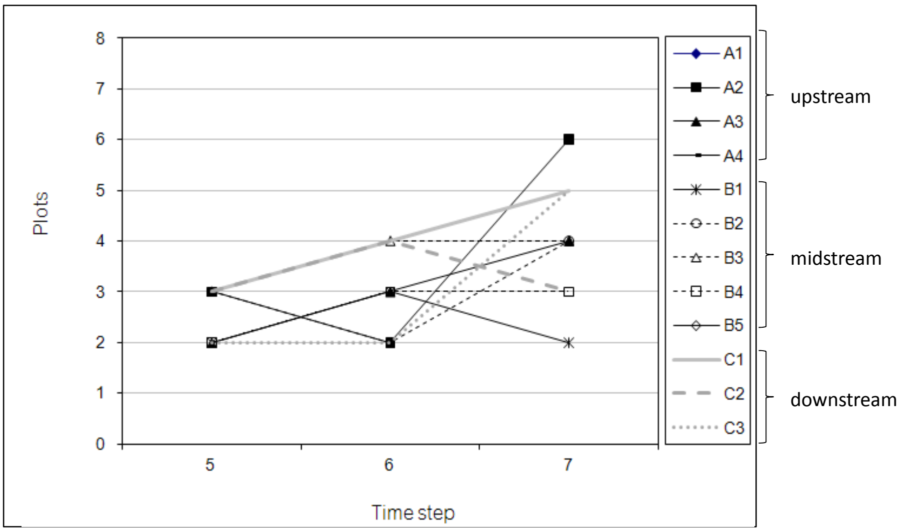


Figure 4.7: The results of the first game session; round 5 to 7, in the morning

Immediately after the game, the moderator invited all players and observers to join a group discussion. The players confirmed that the game based on the "first-come first-served" rule led to unequal water distribution among users, and represented actual water management conditions in their community. They expressed a desire for the emergence of a water sharing agreement in reality, as had happened during the game.

Those elements extracted from the game and the collective dialogue to be integrated into the MAS model (elements and attributes, and scenarios) are as follows:

- The upstream farmer or the farmer with the pipe system has an advantage in accessing water
- Agents who experience water shortages should communicate the problem with others and try to organize a collective discussion
- Iteratively, the discussion process will take some time to reach an agreement on water use regulation, and
- The scenario collectively identified a focus on the equal sharing of water by limiting pipe size or individual cultivated areas.

4.4. Investigation of the Role and Function of Local Institutions

It was found during the discussions that the village network plays an important role in managing natural resources in this area. Consequently, the researcher attended several meetings of the village network to understand better the role of this organization. One objective of the village network is to lower the degree of forest law enforcement, since most of the local farmland falls into the reserve forest category. The village network and the Maehae people assume that better forest management will result in less strict law enforcement. This is one case among others in Thailand where villagers in remote areas, through flexibility in local institutional arrangements, have been able to make compromises and deal with local government officials on issues of clearing land for agriculture and forest access, where state laws would make such activity illegal (Lebel, 2005). The village network, in association with the local RFD officer, has been trying to conserve forest resources to ensure their rights to hold and cultivate their farmland; this is a remarkable case of "good" collaboration in managing forest resources among the RPF's development centers. This role of the village network is well recognized among Maehae village leaders and a number of villagers, and thus explains the players' behavior during the land-forest RPGs.

The village network's committee members are representatives selected from each village, as well as villages leaders (ten Karen and eleven Hmong), and include the local forester and his assistant. They attend monthly meetings to discuss propositions on social development and watershed resources management issues. Most of the problems of land, forest and water management recently brought to the village network monthly meetings have been about the expansion of farmland in the protected forest area and the conflicts over water use; and these problems are closely related. In order to obtain better land and water access, farmers seek new, fertile land in upstream forest areas. This kind of forest encroachment problem always takes more than one meeting to discuss and reach a final agreement on, due to the absence of some committee members (the committee cannot examine the case if less than two-thirds of the committee members attend), and the quality of communication between the village network and the communities (for instance, if the responsible member cannot contact or cannot negotiate with the owner of the new farm plot). In addition, some of these problems might be the result of poor monitoring control, because certain individuals tend to hide the cases of his/her relatives or a social leader. Although the local forester has regularly attended the monthly meetings, decision-makings on reported problems are mainly made among the committee members. The local forester might make a strong statement when he finds newly opened farm plots in an obvious place (for example, beside the road), or when there are too many. Once the final debate takes place, the committee members tend to support the cause of their kin and ethnic group. After the 2004 drought, the issue was discussed by the village committee and villages leaders. An idea to share water equally was suggested, but the village network could not achieve it. The degree of problems and concerns varied among different communities and locations; the village network committee had limited legitimacy and was not able to deal with local power relationships and elite problems.

The land and water conflict problem therefore remained unsolved, and social tension increased when farmers from outside Maehae encroached on to the forest area and cultivated crops in Maehae's upstream area. The village network considered this an urgent problem and sought a solution. On 26th July 2007, the research team facilitated and co-organized a collaborative investigation with the Maehae villages' leaders and the village network committee, in which we surveyed the upstream area where the conflicts occurred and then held discussions to formulate alternative management solutions and rules. Thereafter, a negotiation workshop was arranged among upstream and downstream water-user groups. The Maehae communities' leaders, the local forester, district officers and representatives of the farmers from outside Maehae, as well as the head of the sub-district, were invited. The earlier common management rules were proposed during the negotiations among representatives of upstream and downstream stakeholders. However, they could not reach an agreement since each group claimed ownership over the conflict area, either by use of the official village boundary or due to inheritance. Furthermore, some key representatives were absent from the meeting. On the one hand, the farmers from outside did not have strong evidence to support their right to use the land, and on the other hand some village leaders in Maehae thought that some of the proposed rules might also create more constraints on their own land and water use. This was the first time that this problem was discussed and shared among stakeholders from different organizational units.

As the Maehae social process continued, a series of collective investigations and discussions were conducted at the community level to brainstorm and re-formulate possible solutions (Table 4.6). The propositions were: an equal share of water volumes, limiting the size of the water pipe and prohibition of cropping on very steep slopes and/or close to a stream. On 18th September 2007, the researcher and the village network, as well as the village leaders, organized a collective workshop aimed at sharing knowledge, improving the performance and effectiveness of the village network, and seeking plausible solutions with regard to the land, forest and water management problems. The information synthesized from the previous Maehae collective activities, as well as the overlaying of aerial photographs showing cultivated areas (farm plots and owner) with other state-reserve areas in the Maehae watershed (forest reserve area and restricted watershed classes), were presented to the group to facilitate and stimulate the discussion.

Table 4.6: Collective investigation and brainstorming activities, and number of participants

Date	Activities	Number of Participants
5 Jun 07	Survey a major creek in the conflict area	25
6 Jun 07	Report the 5th June 07 survey and discussion	33
6 Jul 07	Plan for surveying the conflict area	26
26 Jul 07	Survey another creek in the conflict area	36
5 Aug 07	Village committee meeting (Karen)	13
6 Aug 07	Meeting and negotiation	37
25 Aug 07	Village committee meeting (Karen)	9
27 Aug 07	Negotiation	27
5 Sep 07	Village leader meeting (Karen & Hmong)	8
6 Sep 07	Follow up the conflict case	21
14 Sep 07	Village leader meeting (Hmong)	6
18 Sep 07	Collective meeting, facts and situation analysis	24

The negotiation process took a long time; it was difficult to agree upon management solutions. Nevertheless, the Maehae people carried on the process and achieved an agreement on limiting the number and size of irrigation pipes in the upstream area in early 2008, six months after the previous intervention.

4.5 Conclusion on the Investigation Process and its Transition

This chapter explains the participatory investigation process which employed role-playing games and institutional engagements involving various stakeholders at different organizational levels. It aims to understand and verify knowledge on the process of land-water-forest management in Maehae watershed, to enhance collective learning and facilitate dialogue on watershed management. The initial objective of this study was first to clarify the ambiguous representation of land and forest resource management, and second to explore alternative management scenarios. There was a need for a better understanding of the processes at stake and for a common understanding of each stakeholder's point of view. Consequently, the investigation started with the design of a land-forest RPG to verify the knowledge obtained from previous investigations, and to share the understanding of individual and collective behavior, that which drives the dynamics of land use. The agricultural dynamics and the forest management rules were well known; the objective was more to see how each stakeholder, farmers on the one side and the forester on the other side, interacted and coped with the official rules. Lessons learnt from the land-forest RPG and player interviews confirmed that Maehae people and the local forester can compromise over farmland and forest access, as stated in Lebel (2005), but this relationship would vary with a specific context. Due to a period of drought, the focus shifted to the water management problem. The problem for this second step was different; there were no administrative rules for water management and a given player was in charge of verification and enforcement of the rules, as was the case for the forest. Consequently, the workshop on water management was more exploratory. The RPG for this game was a new model and did not include any components of the previous land-forest game; the objective was clearly to explore the reaction of stakeholders facing water shortages and identify and discuss collectively the possible scenarios. After these two different participatory modelling exercises, the knowledge gain was adequate to explain the individual behavior and the watershed dynamics, but the collective dimension of the decision-making process was lacking. Thus, the researcher participated in monthly meetings to understand and grasp the functions of the village network. The researcher facilitated and co-organized focus-group meetings at the village, village network and inter-institutional levels, which helped to formulate management plans and scenarios. Figure 4.8 summarizes the evolving investigation process, engaging a multi-party institutional level of stakeholders.

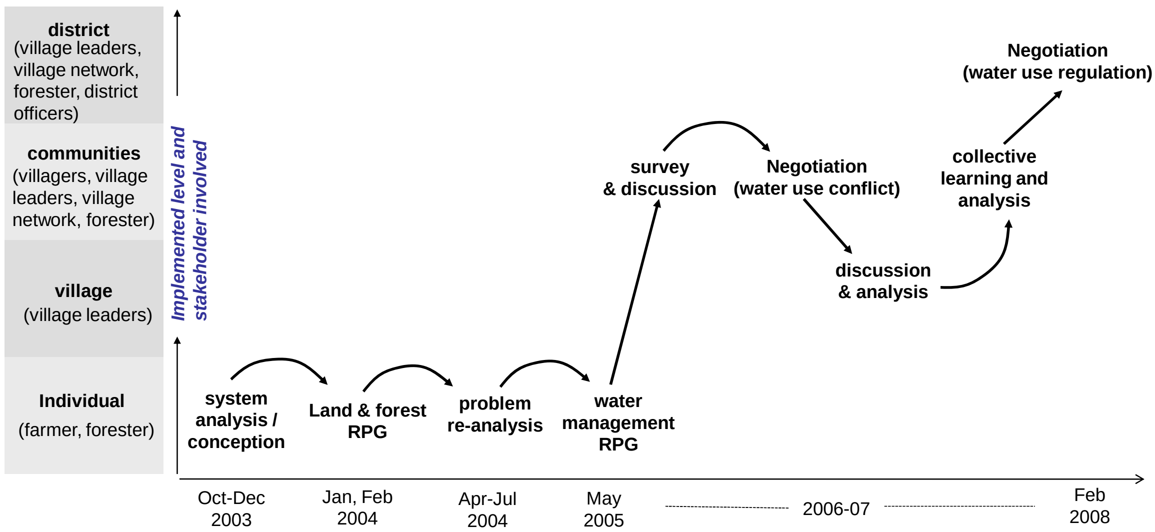


Figure 4.8: Successive steps and implementation levels for the evolving ComMod processes implemented in Maehae, Chiang Mai Province: 2004-2007

Chapter 5: The Multi-Agent based Model and Simulation

5.1 From Field Investigations to the Model

The previous chapter explained the participatory investigation process which employed a role-playing game and institutional engagements involving various stakeholders on a multi-organizational level. The findings reveal and answer the question set earlier on how people in Maehae and the forester manage resources under a situation of conflicting goals and objectives. The outcomes were also extended to deal with social concerns and awareness on watershed resource use and management within multiple stakeholders' interests, and to take on multiple scales. This facilitated and stimulated the social aspects of problem analysis and the deliberations held to resolve the resource use conflict problem collectively. Common perspectives toward problem-solving given during the field investigation can be categorized into two aspects: one is the ideal of equal water sharing, and another direction is imposing water use regulations, under which an agreement on limiting water use in the upstream areas was made, out of negotiations among upstream and downstream water users.

Of scientific interest, the outputs from these implementations are improved understanding and verification of the knowledge existing on land, water and forest management across multiple stakeholders in the Maehae watershed. This understanding helps to explains how individuals behave, make decisions and interact with one another. It also extends to cover the functioning of the village network, the tasks and actions of the committee members when dealing with land, forest and water management problems. This knowledge can be documented and shared in a narrative way to explain the socio-ecological context of the Maehae watershed system. However, this can only cover a certain extent of its complexity, and under certain situations, because there are number of uncertainties involved in determining system dynamic and change; especially in this study, such as the behavior of individual actors, the functioning of the village network, as well as interaction between these two levels; their affects and responses to the environment. Moreover, this cannot provide informative direction and detail when questioned on what the system would be under such resource management and rule configurations. Therefore, a simulation model was developed in order to: 1.) reproduce the common representation of the Maehae system - to better understand the interaction between individual actors and local institutions with regard to resource use and management, and 2.) to explore individual and collective roles within alternative resource managements and rules. In addition to the previous findings, seasonal crop yields and prices and crop yields were gathered to develop the MAS model.

This chapter provides a linkage between the knowledge acquired from previous investigation activities and the supplementary data, and the MAS model conceptualization and design. It then describes the model structure and its components - both agents and environmental entities, and this helps to give an idea on the scale and context of this virtual system. The next phase provides state variables of the model entities, input data and the sequences of the model simulation; then elaborates on details of the agents' roles and interactions, and the processes and dynamics of environmental entities.

The last session explains scenarios developments to explore how the performance of the modeled system changes under alternative resource management strategies regarding the ideal or theoretical water management, the actual resource use and management at stake, and the adaptive resource management. The simulation results are analyzed and compared using selected indicators to express and compare the system performance and properties among different scenarios.

5.2 The Model Description

As a result of these participatory processes, the data regarding key stakeholders, their main characteristics and interactions were synthesized and assembled into an MAS model, to explore alternative management scenarios. Agents and their behaviors, major environmental components and attributes, as well as management scenarios derived from the previous investigation and inquiry processes, are presented in Table 5.1.

Table 5.1: Model components and their characteristics resulting from previous investigations

Investigation Tool	Outputs Used in the Model
Preliminary system analysis	- Agents (farmers, forester and village network) - Environmental components (farmland and forest) - Perceived factors included in the decision-making process (crop products, crop prices, rainfall, forest area, new farm plots, average cultivated farm size)
Role-playing game	- Agents' behaviors: decisions, communication and interaction - Management rules - Simulation indicators (cash income, the number of cultivated and failed plots, new farm plots, amount of water and forest area)
Focus group discussion and interviews	- Common concerns and problems (water scarcity and conflict)
Participation in the village network meetings	- Group interaction and the collective decision-making process
Co-organizing and facilitating collective investigations, workshops and negotiation meetings	- Alternative management scenarios for resolving resource use conflict. - Agents' interactions in the debating process. - Need for strengthening the village network function.

In order to transforming the preset Maehae socio-ecological conceptualization into an MAS simulation model, the model design began with defining main actors or agents, both individual and group; their behaviors and roles, and the interactions between them. The environmental components are those land, forest and water resources that the actors perceive and interact upon. These design components were related to and transformed from the system conceptualization explained in the previous chapter. The model simplifies and reproduces land-forest and water management of the Maehae watershed. The agents are heterogeneous farmers, different in ethnicity, social and economical status; and there is also a group agent representing the local social organization (the village network). The environment components are farmland, forest area and water resources, representing geographical space at the sub-watershed level.

The major processes in the model are the agent's actions and communication, which cover individual and group decision-making for resource management, and the biophysical dynamic process. For the latter, the driving factors are rainfall, available water and land cover type. The main outputs of the process are crop production, the amount of water availability, the number of cultivated plots, failed crop plots, new farm plots and cash-income balance. The model developed for this study is called the "Maehae model"; MHM.

5.2.1 The Model Description Framework

This section aims to provide a model description, as well as information to explain the structure and processes of the developed simulation model, enough for other disciplines to understand and for other modellers to reproduce and use the model. The model to model issue is considered important among researchers utilizing Multi-Agent-Based Simulation (MABS) when exploring complex social, biological and artificial systems, as this allows others to interpret and re-implement the created model (Hales et al., 2003); however there is no standard protocol set. Grimm et al. (2006) proposed the ODD protocol (Overview, Designed Concepts, Details) to initiate a common format for the description of the agent-based model (ABM). The ODD protocol was formulated among modelers in the fields of ecology; it formulates the model description into seven elements, terms and description sequences that well explain the common individual-based modeling for ecological dynamic systems. In order to explain the MHM that addresses the communication and interaction between different levels, and the decision-making of social agents, the MHM description framework used in this chapter is adapted from the ODD protocol, the order and detail of the description elements have been adjusted to illustrate the specific context applied to the MHM and provide other non-MABS-modelling disciplines with a better understanding of the modeled system. In addition, the Unified Modelling Language (UML) diagrams are used to depict the process sequences and the detail applied in the model (Booch el al., 1999). A general story of the MHM is given before moving on to the model's description, as this helps relate the model description with the context and phenomena of the Maehae system.

5.2.2 The Story

The designed model tries to capture the cropping system in Maehae, where farmland and water uses for agriculture, individual and collective actions in managing the forest and water resources, are linked to performance of the whole watershed system. The dynamics and properties of the system in the model can be observed and analyzed to reflect agricultural productivity, economic returns and resource availability.

The processes in the MHM exemplify the story of Karen and Hmong farmers who are cultivating crops in a watershed area. Their farmland is scattered across different locations and has varying topographical characteristics; the main crops are rice, vegetables and fruit, though the farmers grow paddy rice during the rainy season for their staple food. Vegetables and fruit orchards are temperate crop types introduced by the Royal Project Foundation. Vegetables can be grown in the paddy fields after rice, and also on other sloping farmland, and those farmers who have abundant farmland and enough cash may invest in setting up fruit orchards. The cultivated area is limited by farm size, household labor availability and expected water availability. Thus in the rainy season, farmers tend to cultivate more land than in other seasons.

The farmers use water pipes to divert water from streams to irrigate their farms, using gravity. Therefore, farms located in the upstream areas have a priority in terms of irrigation, over those at lower altitudes; the so-called “first-come, first-served” water access rule. The amount of stream water is determined by rainfall, which fluctuates across seasons, and is more or less unpredictable. Each of the cultivated farm plots demands the same amount of water from both rainfall and stream water. During the dry and cold season, if the stream water is not enough to supply all the cultivated plots, some farm plots in the downstream areas fail and do not yield products. After crop harvesting, the farmers sell their products to the market - for a cash return, though crop price fluctuations across all the cropping seasons are determined by the external market. The farmer’s satisfaction regarding his or her cash income balance and crop failure experiences, influence changes in farm management decisions; farmers may adjust their farm plans by reducing the cultivated area so as to avoid a water deficit risk, or may make a request to the village network to help resolve the problem, or they may establish new cultivated land in upstream areas to ensure they receive irrigation water, but this is perceived as being ‘prohibited’ according to the rules set by the village network, as well as the state forest and watershed protection laws.

Routine farm activities of the farmers include going to and working on the farm, and they are able to observe part of the watershed to look for land use changes, such as forest encroachment for creating new farmland, and they may communicate and share this information with each other. Some of them are also village representatives, as well as members of the village network committee. Thus, information on the newly established farmland will be conveyed to the village network meeting.

The forest protector, who is responsible for conserving the forest area in this watershed, also observes the watershed and may communicate and interact with the village network when he finds that there are too many new farm plots.

Every month, the village network sets up a meeting to discuss and consider the forest encroachment and water deficit problems. If a new farm plot case is reported, the committee members will discuss and debate the issue; they may allow the new plot to exist if the owner is poor and holds a small farm area, otherwise they will vote to withdraw the plot and fine the owner according to the common regulations set at the establishment of the village network. This village network function and its rules are known to all the farmers; however, the small-scale farmers and those who are faced with crop failure problems due to water deficits, may again try to establish a new farm plot in an upstream area.

5.2.3 Overview

The Maehae model (MHM) is a spatially explicit model implemented in Cormas (**co**mmon-pool **r**esources and **m**ulti-**a**gent **s**ystems). Cormas is a simulation platform based on the VisualWorks programming environment, which allows the development of applications in the object-oriented programming language Smalltalk. Cormas pre-defined entities are Smalltalk generic classes from which, by specialization and through refinement, users can create specific entities for their own model (http://cormas.cirad.fr/indexeng.htm). Cormas was designed to accommodate the MAS model development, one that focuses on natural renewable resource management with multiple agents that take actions on decision-making, control and communication. It provides a platform to develop agents, the environment and passive objects that fit to the representation of the modeled system.

5.2.4 Purpose of the Model

The purpose of the MHM in general is to represent and simulate the interaction between individual farmers, the village network institution and the forest protector with respect to the temporal and spatial changes of resources use and management in a watershed. In addition, the extended objective is to use the model to explore variations of control factors and parameters in the processes of observation, communication and village network functioning, that contribute to simulation outputs in terms of agricultural production, economic revenue and the availability of land, forest and water resources.

5.2.5 MHM Structure: Object Classes, Attributes and Scale

The MHM is structured by individual and institutional agents that interact with each other within the spatial environment. Table 5.2 explains the agents, environmental components and other objects in the MHM, compared to the real world entities they represent.

Table 5.2: Object classes in the MHM and real world entities representation

Agents & Objects	Real World Entity
Farmer	Maehae farmers
ForestProtector	The local official forester
Village	Village
VillageNetwork	The Maehae village network
LandUnit	Minimum land unit which can be aggregated into farmland, forest, water bodies and roads.
LandusePlot	Farm plots aggregated from the land unit; one plot equal to 0.5 rai (land unit in Thailand; 1 rai is approximately 0.16 hectares)
Farm	Farm that is composed of farm plots
Watershed	The whole watershed
Water	Water availability
Rainfall	Rainfall
Market	Crop market that determines crop investment costs and crop product costs.

The UML class diagram in Figure 5.1 shows object classes and their associations in the MHM model. There are three groups of object classes: 1.) spatial objects which are *LandUnit*, *LandusePlot*, *Farm* and *Watershed*, 2.) the agent classes consisting of *Farmer and ForestProtector*, the communication agent, *Village* and *VillageNetwork* and the group agent classes, and 3.) passive object classes which are *Water*, *Rainfall*, *Parameters and Market* classes, that provide auxiliary data and parameters for model simulation. Each object class has attributes or variables that describe its state; for the interactive agents these influence the action and decision-making process. In addition, some of the variables can be manipulated to express the state of the global level of the system. The detail of object classes and attributes is explained in the following sections.

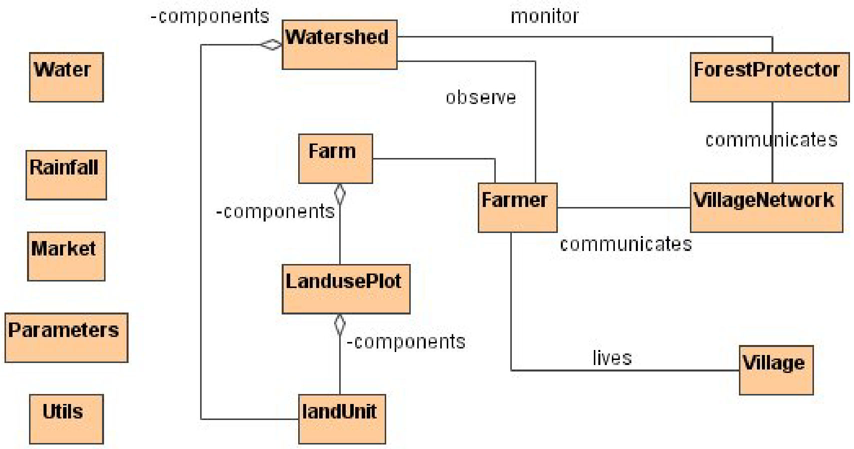


Figure 5.1: The UML class diagram of the MHM without attributes and controls

The MHM model focuses on *Farmer* and *VillageNetwork* roles in utilizing and managing *Farm* (land and forest) and *Water* in a *Watershed*. Farmers choose and cultivate crops on *LandusePlots* in their *Farms,* and use *Water* to supply the crops. Crop production is determined by spatial location of the *LandusePlot*, based on a “first-come, first-serve” water access rule, *RainFall* and *Water*; farm cash income is varied based upon the type of crop, *Market* price and investment cost, and *Farmers’* satisfaction is assessed with regard to farm production and cash income. Due to limitations on the *Water* amount (also *Rainfall*) during the dry season (cold and hot season), crop failure may occur in some of the cultivated *LandusePlot(s)*; this phenomena influences *Farmer* to adjust their farm plan by reducing the number of cultivated *LandusePlot(s)*, establish new *LandusePlot(s)* in the upstream *Watershed* area, or ask for help from the *VillageNetwork.*

An important collective role of the *Farmer* is to observe the *Watershed* and look for new *LandusePlot(s)*, disseminate information on any new *LandusePlot(s)* found, and crop failure problems due to water shortages, and attend monthly meetings of the VillageNetwork in order for it to consider the reported problems. The decision made by the VillageNetwork will affect the accessible water amount and remove and fine the owner of the new *LandusePlot*.

The simulation time step is one month, because the MHM does not use real empirical data and complicated water dynamics and crop growth sub-modules; *Water* quantity and *Rainfall* amounts are held in a virtual unit, the crop-water requirement is simply set to one unit per cultivated *LandusePlot* for every time step. In particular, the model simulation aims to explore the collective action of farmers through the *VillageNetwork* function, an activity that takes place monthly.

5.2.5.1 Spatial Entities

The MHM is a spatially-explicit model which is based on a grid-cell system. There are three classes of spatial entities in the MHM, which are *LandUnit*, *LandusePlot* and *Farm*. *The LandUnit* is the minimum unit of the spatial entities; it can represent other object classes as specified by an attribute that determines the land cover type, for example forest, farmland, streams and roads. The streams and roads are a static aggregation of the *LandUnit*. The *LandusePlot* is an aggregation of the *LandUnit*, and the *Farm* is aggregated from the *LandusePlot.* Figure 5.2 illustrates the associations between these spatial objects.

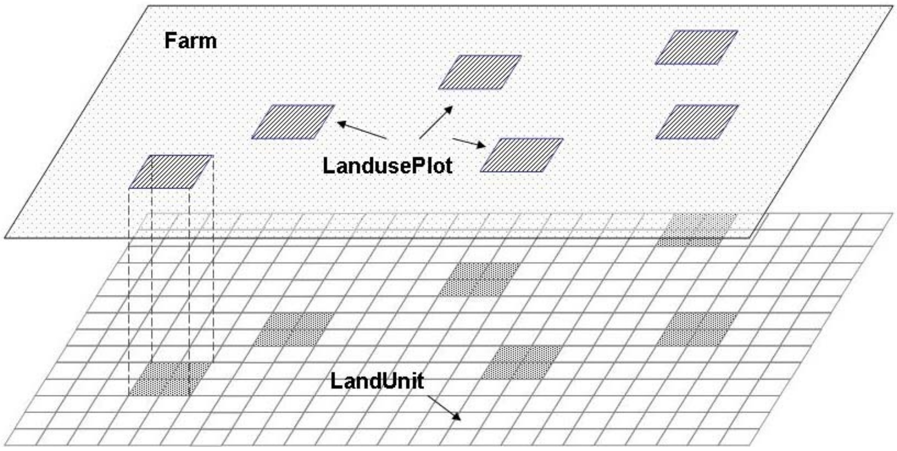


Figure 5.2: The spatial entities in the MHM

These three spatial entities can be changed as part of the simulation in terms of their attributes and components (spatially). For example, a *LandusePlot* can be created or removed, added to and removed from a *Farm* component or to reflect spatial changes; land cover type dynamics of the *LandUnit* and *LandusePlot* are the attribute changes. The main attributes and description of these spatial entities are detailed in Table 5.3.

Table 5.3: The main spatial classes and the main attributes

Class	Attributes and Type	Description
LandUnit	land cover type (N)	The code determines land cover type (crops, forests, streams and roads)
	LandusePlot (O)	The *LandusePlot* (if) it belongs to.
	slope (N)	Slope class, ranges from 1 to 4
LandusePlot	land cover type (N)	Land cover type code
	my *Farm* (O)	The *Farm* it belongs to.
	slope (N)	Average slope class, calculated from all *LandUnit* it is composed of a range from 1 to 4
	water demand (N)	Amount of water demand
	water supply (N)	Amount of water supplied to the plot
	crop age (N)	Age of cultivated crop (month)
	new plot (B)	Becomes true if it is newly created plot
Farm	LandusePlots (O)	All LandusePlots in it.
	my Farmer (O)	The *Farmer* it belongs to
Watershed	forest area (N)	Total forest area

Note: N = number, O = object, B = Boolean

5.2.5.2 Farmer

The *Farmer* class represents individual farmers, each of them can be relatives of one other, belongs to a *Village*, and those who represent the social leader will be also a member of the *VillageNetwork*. The main attributes and description of the spatial entities in the MHM are detailed in Table 5.4.

Table 5.4: The main attributes of the *Farmer* class

Attributes and type	Description
my farm (O)	The Farm
newPlotFound (O)	Collection of the new *LandusePlot(s)* found from observation and the dissemination of information between *Farmers*
ethnicity (N)	Ethnicity code number (1 = Karen, 2 = Hmong)
social leader (B)	Is the *Farmer* a social leader? (also member of the *VillageNetwork* committee)
farm record (N)	Number experiencing crop failure
rice stock (N)	Amount of rice stock (kg)
cash (N)	Cash income balance
satisfaction (B)	Self-assessment results on farm production and cash income balance
sanctioned (B)	Has the *Farmer* been sanctioned by the VillageNetwork due to creating a new plot?

Note: N = number, O = object, B = Boolean

5.2.5.3 ForestProtector

The *ForestProtector* is the communication agent class; there is only one entity in the model. The major role of *ForestProtector* is to monitor and conserve the forest in the watershed area. Its attributes and description are detailed in Table 5.5.

Table 5.5: The main attributes of the *ForestProtector* class

Attributes and Type	Description
newPlotFound (O)	Collection of the new *LandusePlot(s)* found from observation.
observChance (N)	Chance of observing the *Watershed* to look for a new *LandusePlot* (default = 0.5)

Note: N = number, O = object.

5.2.5.4 VillageNetwork

The *VillageNetwork* is the group communication class composed of members who are *Farmers* who are social leaders. Table 5.6 shows the main attributes of this class.

Table 5.6: The main attributes of the *VillageNetwork* class

Attributes and Type	Description
memberJoinMeeting (O)	Collection of *Farmers* who come and attend the meeting
newPlotFoundReported (O)	Collection of new *LandusePlot* found reported by the members
releasedRuleNRM (O)	Water use rule to be implemented.

Note: O = object

5.2.5.5 Rainfall

The *Rainfall* class provides a set on monthly rainfall during the rainy season from three rainfall conditions, which are “good”, “normal” and “drought”, as the virtual amount of 50, 40 and 20 units respectively; the rainfall conditions will be randomly chosen at each simulation step. The *Rainfall* amount beyond the rainy season is set to zero.

5.2.5.6 Water

The *Water* class represents a kind of water tank that stores amount of water obtained from the Rainfall and monthly stream-water released specified by the *Parameters* class with the default value of 20, and this value will be added up with 80 percents of the *Rainfall* amount. The total *Water* amount, then will be supplied to the cultivated *LandusePlot*. Main attributes of the *Water* class are shown in Table 5.7.

Table 5.7: The main attributes of the *Water* class

Attributes and Type	Description
amountEqualShared (N)	Water amount applied in the scenario "equal water sharing"
storage (N)	Collection of the new *LandusePlot(s)* found reported by the members.
waterMonthlyReleased (N)	Amount of stream-water; released monthly (default = 20)

Note: N = number

5.2.5.7 Market

The *Market* class provides monthly crop price data, crop investment costs and average crop yield. The monthly crop prices data contains low, average and high prices, derived from empirical monthly crop price data from the Maehae Royal Project Development Center during the years 2004 and 2005; the crop price applied in each simulation time step is varied by crop price conditions, which are randomly chosen from "good", "medium" and "low" price conditions. The crop investment costs data are varied on a monthly basis, this data set is adjusted from secondary data as well as the data applied to and verified in the role-playing game sessions. Attributes of *Market* class are listed in Table 5.8.

Table 5.8: The main attributes of the *Market* class

Attributes and Type	Description
cropPriceCondition (N)	Market crop price, randomly chosen from {1 2 3 1 2 1}; price condition 1 = low, 2 = medium, 3 = good
cropPriceData (O)	Monthly crop price data (collection)

Note: N = number, O = object

5.2.5.8 Parameters

The *Parameters* class assigns parameters and threshold values for several methods applied during the simulation. Some of these values are fixed and some are randomly chosen from certain ranges. The main attributes of the *Parameters* class are listed in Table 5.9.

Table 5.9: The main attributes of the *Parameters* class

Attributes and Type	Description
observableRange (N)	Range (number of LandUnit) that the Farmer can observe (environment, or see the others) from a place, selected randomly from the collection (15, 20, 25, 30)
fineForNewPlot (N)	Cash amount of the penalty applied for creating a new plot (default = 3,000 baht).
thresholdNewLanduse (N)	Maximum number of the new LandusePlot(s) found that makes the ForestProtector report to the VillageNetwork (default = 8 plots)
chanceAbsentMeeting (N)	Chance of the member of the VillageNetwork being absent from the monthly meeting, selected randomly from the collection (0.3, 0.4, 0.5)
chance2MeetNewPlotOwner (N)	Chance of success in negotiating with the Farmer who owns the new plot, selected randomly from the collection (0.3, 0.4, 0.5)
lobbying (B)	Lobbying during the vote
maxPlotsCanBeRemoved (N)	Maximum number of new plots that can be withdrawn from one farmer in each time step (default = 1)
maxWaterRulePipeSize	Maximum water pipe size that determines the amount of water units allowed for each Farmer, as the result of the VillageNetwork water rule imposed (default = 5).
minWaterRulePipeSize	Minimum water pipe size that determines the amount of water units allowed for each Farmer, as a result of the VillageNetwork water rule implementation (default = 2).
sanctionPeriod (N)	Sanction period, months (default = 0, or no sanction)
waterMonthlyReleased (N)	Amount of water units given to the Water, monthly (default = 20)
consumeRiceYearly (N)	Amount of rice each Farmer consumes yearly (default = 300 kg)
cropWaterDemand (N)	Number of water units each cultivated LandusePlot demands, monthly (default = 1)

Note: N = number

5.2.6 Processes and Scheduling

The MHM simulation proceeds in a monthly time step, and the main processes are illustrated using the UML sequence diagram shown in Figure 5.3. The vertical line represents the time, beginning from the top to the bottom. The rainfall, water and market will be updated to determine the amount of rainfall, the available water and crop price respectively, for each simulation step. There are four major sequential activities of the agents in the model which are observing the watershed, disseminating information among the farmers, managing farms and the village network meetings and functioning. The diagram does not include sub-procedures and details on decision-making processes and determinant parameters embedded inside each main process; these will be illustrated later in the details description section in this chapter.

5.2.6.1 Input Data Update

At the beginning of each time step, the rainfall, water and market price input data will be updated according to the month and season. The input data detail will be explained in the input section.

5.2.6.2 Farmer observesNewLandusePlot

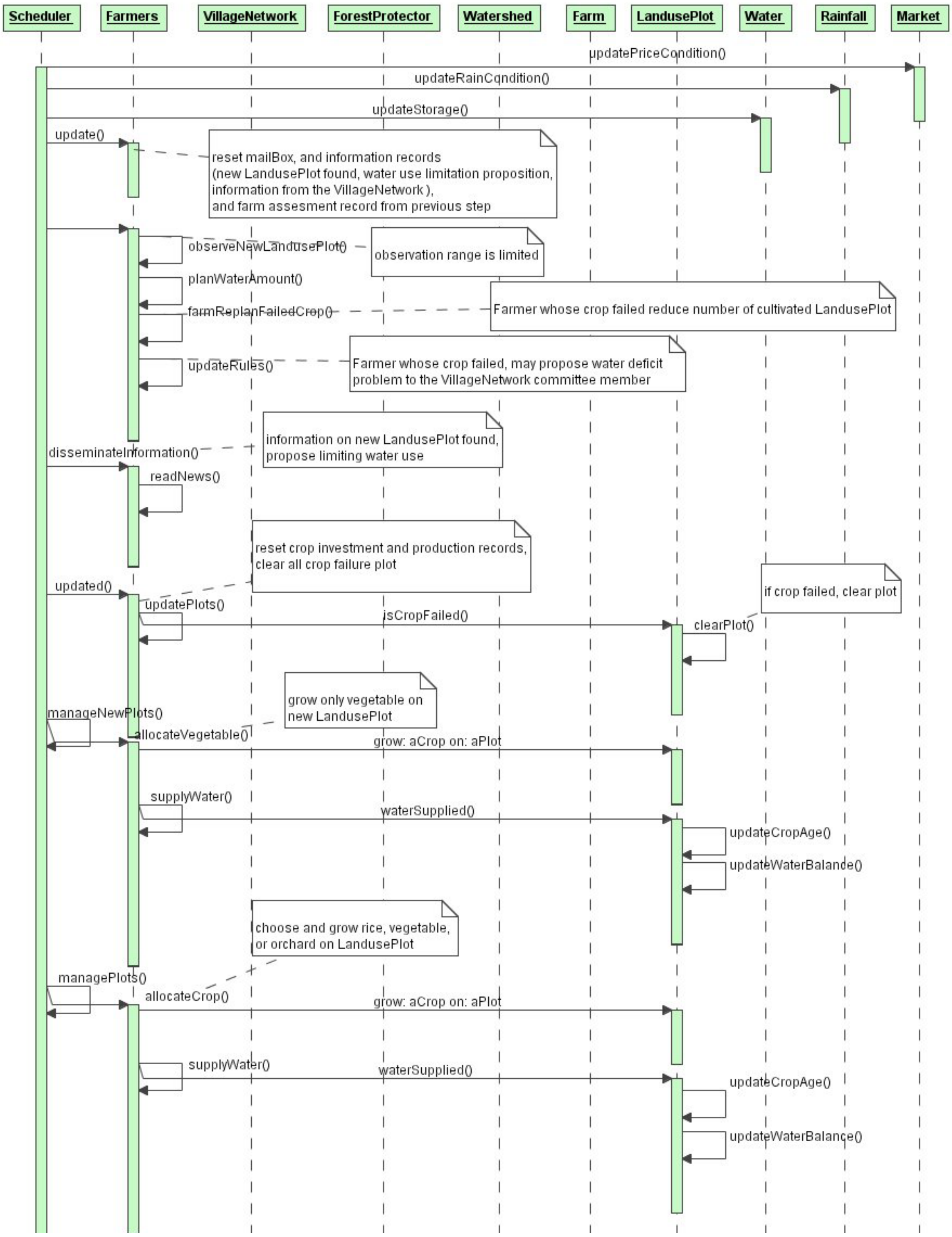
The first action of the *Farmer* is observing the *Watershed* area to see if there are any new *LandusePlots* created by other *Farmers* that have expanded *Farm(s)* into the forest area. The *Farmers* can observe the area along the road, as well as the area near their *Farm(s)*; the distance that determines the capability of observation is the number of spatial grid cells specified in the *Parameters* class, a value randomly applied during simulation. In the model, as in reality, the farmer knows who the owner of such a new plot is; however, the *Farmer(s)* ignore their own new *LandusePlot*.

5.2.6.3 Farmers planWaterAmount

The *Farmer* assumes a water amount that is available in each time step, a factor which is varied in different scenario configurations. In general, the *Farmer* assumes that the water amount is enough to supply all cultivated *LandusePlot(s)* as if it were the rainy season where the water is abundant; the assumed water amount is stored in the attribute *myWater* of the *Farmer*. If a water rule is imposed by the *VillageNetwork*, the Farmer's *myWater* is set according to the limited irrigation pipe size which determines the maximum water units each *Farmer* is allowed to use.

5.2.6.4 Farmer farmsReplanFailedCrop and updateRules

The *Farmer* records the occurrence of crop failures that happened in previous time step due to a water deficit problem, and adjusts the farm plan by reducing one cultivated plot each time, but the minimum cultivated plot should not less than two. In addition, but this depends on the scenario configuration; the *Farmer* may plan to make a complaint to the member of the *VillageNetwork* committee.


Scheduler
Farmers
VillageNetwork
ForestProtector
Watershed
Farm
LandusePlot
Water
Rainfall
Market
updatePriceCondition()
updateRainCondition()
updateStorage()
update()
reset mailBox, and information records
(new LandusePlot found, water use limitation proposition,
information from the VillageNetwork),
and farm assesment record from previous step
observeNewLandusePlot()
observation range is limited
planWaterAmount()
farmReplanFailedCrop()
Farmer whose crop failed reduce number of cultivated LandusePlot
updateRules()
Farmer whose crop failed, may propose water deficit
problem to the VillageNetwork committee member
information on new LandusePlot found,
propose limiting water use
disseminateInformation()
readNews()
reset crop investment and production records,
clear all crop failure plot
updated()
updatePlots()
if crop failed, clear plot
isCropFailed()
clearPlot()
grow only vegetable on
new LandusePlot
manageNewPlots()
allocateVegetable()
grow: aCrop on: aPlot
supplyWater()
waterSupplied()
updateCropAge()
updateWaterBalance()
choose and grow rice, vegetable,
or orchard on LandusePlot
managePlots()
allocateCrop()
grow: aCrop on: aPlot
supplyWater()
waterSupplied()
updateCropAge()
updateWaterBalance()

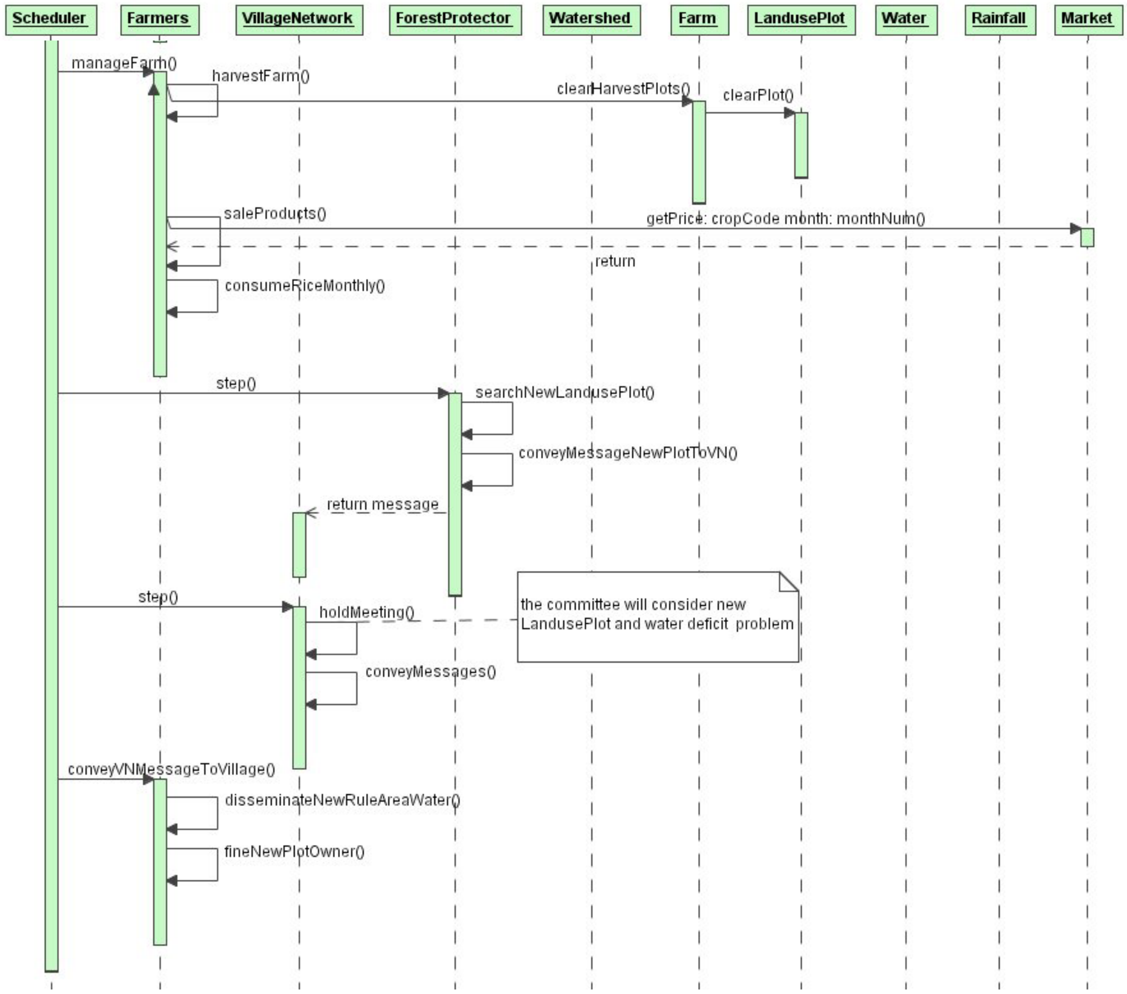


Figure 5.3: Sequence diagram showing the main processes in the model

5.2.6.5 Information Dissemination

There are two kinds of information the *Farmer(s)* disseminate to the others; one is about the new plots found, and another one is the complaints on water deficit problems. After monitoring, the *Farmer* disseminates the findings to his kin, the owner of his neighboring *Farm* whose farm is located within the observation range specified in the *Parameters* class, and the social leader who is also a member of the *VillageNetwork* committee. The information might be discarded depending on the possibility of communication and the development of a relationship between them, for example, a *Farmer* would disregard a new *LandusePlot* case when the land is owned by the leader or his kin. The *Farmer* who is also a member of the *VillageNetwork* collects his own observations and receives cases transmitted to him by other *Farmer* observations, and conveys this information to the *VillageNetwork*. In addition, if the *ForestProtector* finds that the number of new *LandusePlot(s)* is too many (eight plots or more), he will bring all cases to the *VillageNetwork*. For the *Farmers* facing a crop failure problem caused by a water deficit, they may report and make the complaint to the social leader to bring the problem issue to the attention of the *VillageNetwork* committee.

5.2.6.6 Creating a New *LandusePlot*

The *Farmer* who has experienced crop failure in a previous time step may decide to establish an additional new *LandusePlot* in an upstream area, in order to have better water access for irrigating vegetable crops. However, the *Farmer* who is being sanctioned by the *VillageNetwork* cannot create the plot unless the sanction period is over.

5.2.6.7 Farm Management

Farm management is initiated at the model level because the water supply rule used in the model is the "first-come, first-served" rule, thus the *LandusePlot* is managed in order, from upstream to downstream; and when each *LandusePlot* is selected the model sends a request to the owner *Farmer* to manage it. The *Farmer* allocates only vegetables to the new *LandusePlot*, because that is the reason for establishing the new plot in the upstream area, For the rest of the *LandusePlot(s)*; the *Farmer* may grow rice, vegetables or fruit. Figure 5.4 illustrates how the *Farmer* manages the new *LandusePlot*.

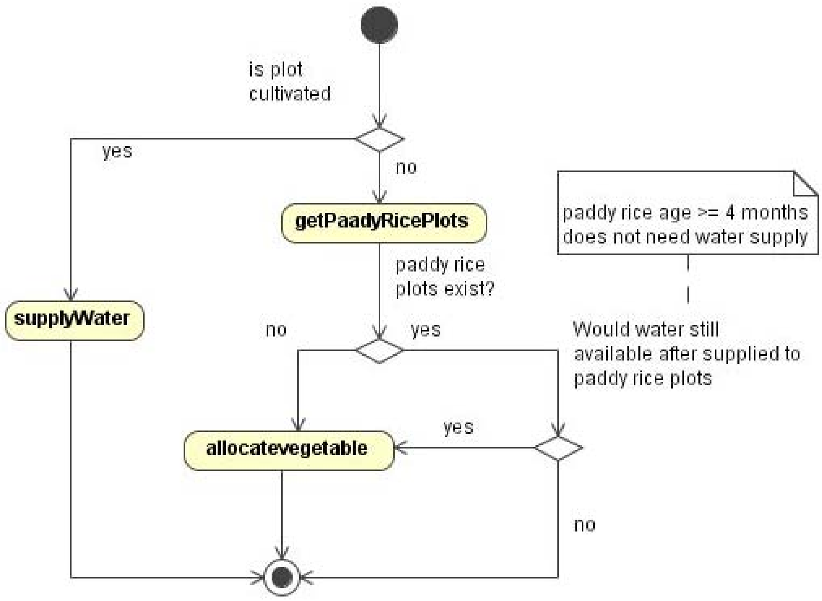


Figure 5.4: The manageNewPlots UML activity diagram of new LandusePlot management

According to the common farm management practices of the Maehae farmers, as gleaned from farmers' interviews and the farm plots survey data, a farmer will cultivate and manage farm land to a maximum of six plots concurrently (excluding paddy rice and orchards), and the maximum number of vegetable plots is four, due to the available household labor and cash available for crop investments. Thus, this common practice is applied in the MHM. Each time step the *Farmer* chooses, then cultivates crops in the *LandusePlot*. The *Farmer* cultivates the number of *LandusePlot(s)* according to the water availability he assumes (*myWater*). Before cultivating an additional *LandusePlot*, the *Farmer* has to reserve or supply water to the existing cultivated *LandusePlot(s)* in the *Farm*; if the *Farmer* assumes that there will be enough water left, then the he or she decides to cultivate an additional *LandusePlot*. However, if the *Farmer* has experienced crop failure due to water shortage before, he will reduce the number of expected cultivated *LandusePlot(s)* by one plot. The UML activity diagram of managing such a LandusePlot is presented in Figure 5.5.

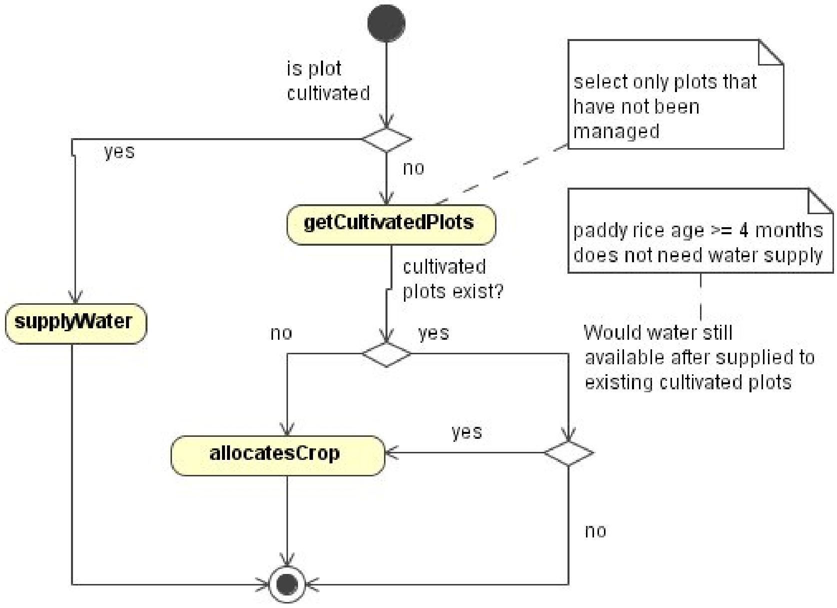


Figure 5.5: UML activity diagram of the *managePlots* function

The available crop choices are paddy rice, upland rice, lettuce, red cabbage, cabbage, Chinese cabbage, parsley, pointed cabbage, zucchini and also fruit, which is persimmon. The chance of choosing each crop corresponds to the common practice and preference of the Maehae farmers. L lettuce is the first choice for the farmer, if it is already grown on the farm, another crop will be randomly chosen but not the existing one, thus the *Farmer* tries to select vegetables that are not being cultivated on the farm. In addition, the *crop* choice and allocation are co-determined by season, location and the slope of the *LandusePlot;* the plots in upstream areas will be managed first. There are four possible slope classes, valued from 1 to 4. The *Farmer* gives priority to the *LandusePlot* in the lowland areas (slope = 1). All the lowland plots will be allocated or reserved for paddy rice during the rainy season (meaning that the *Farmer* will not utilize lowland areas during the period of two months before the rainy season), and for vegetables after the rainy season, vegetables can be grown on every slope, but the *Farmer* will not develop fruit orchards in the lowlands. The process of farm management and decision-making with regard to crop choice and allocation is illustrated in Figure 5.6.

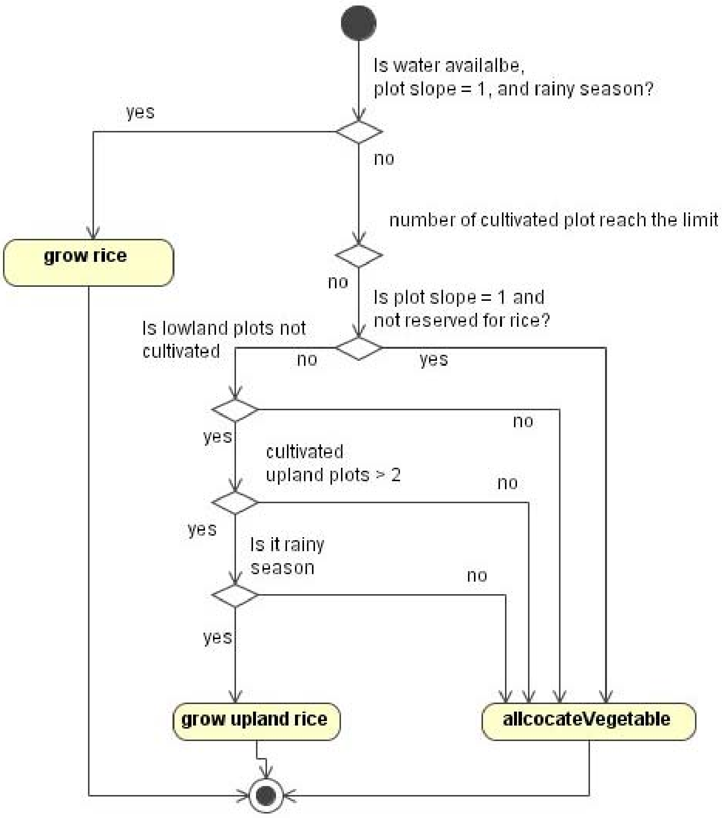


Figure 5.6: The allocateCrop decision making diagram on crop allocation in the common LandusePlot

The vegetable and orchard allocation decision-making process is illustrated using the decision making diagram in Figure 5.7.

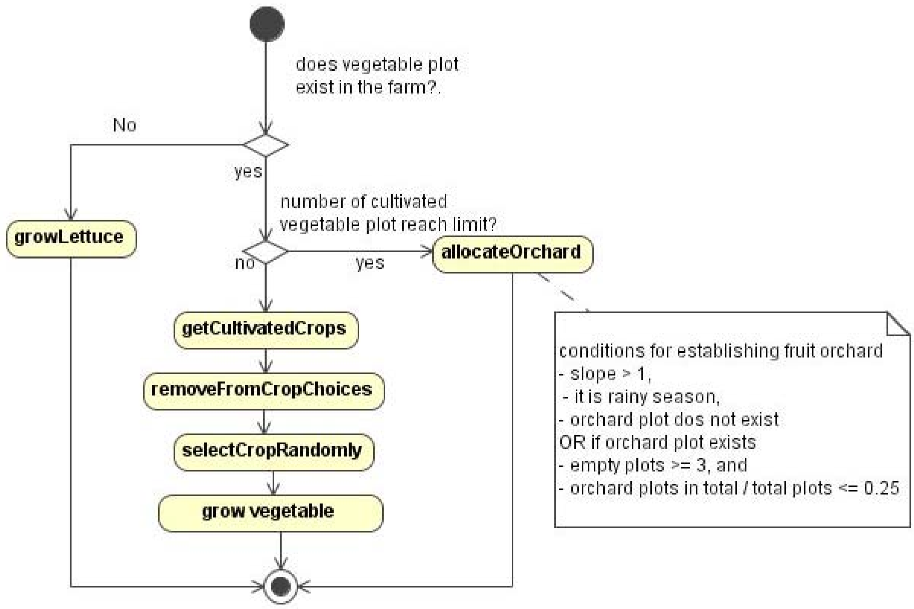


Figure 5.7: The allocateVegetable UML activity diagram explains the decision-making process for vegetable and fruit orchard allocation

The investment costs for cultivating crops, the harvesting period, and the average crop product and crop price, are varied along with the growing season. In the MHM, the *Farmers* are allowed to grow vegetables although their cash income balance is negative, because the model is explicitly designed to constrain water availability and cause a crop failure; as this situation stimulates the individual and collective actions required to alter the landscape by establishing new *LandusePlot* and *VillageNetwork* interventions in withdrawing the new plots and formulate the water rules required to limit water use.

The *Farmer* whose *LandusePlot* is located in the upstream area has a priority to access water to irrigate his or her cultivated *LandusePlot* over the other *Farmers* whose plots are located downstream; the so-called "first-come, first-served" rule. This privilege in accessing the water is derived from the water management behavior demonstrated in the water role-playing game and the discussions held during the field investigation. However, water will be supplied to paddy rice prior to other crops, which corresponds to the real life practice of the Maehae farmers. At the end of each cropping season, the *Farmer* harvests crops, and crop yields are derived from the average monthly crop productions data collected by the Maehae Royal Project Development Center. The crop yield is also determined by the amount of available *Water* supply; a crop failure occurs when there is not enough water to supply the *LandusePlot* and the crop product is completely lost. Crop product price data, and crop input costs from the *Market* are used to calculate cash returns and the cash income balance of the *Farmer* after harvesting. However, paddy rice and upland rice products are not sold, but are stored as part of the rice stock, for consumption. The *Farmer* needs to buy rice if the rice stock does not meet the monthly consumption requirement, which is equal to 75 kg for an average household size of three people, where the average rice consumption rate is approximately 300 kg/person/year.

If a *Farmer* experiences a water shortage problem (crop failure) more than two times consecutively, and he again faces a dry season, he reduces the size of his cultivated *LandusePlot* to avoid the risk. The *Farmer* who experiences a water deficit problem and/or has a negative cash income balance, may seek a new *LandusePlot* in the upstream area, or ask the village leader to seek a solution during a *VillageNetwork* meeting to solve the water deficit problem. The decision making on creating a new *LandusePlot* and/or asking for help to resolve the water deficit problem, is explained in the *VillageNetwork* function section.

5.2.6.8 ***ForestProtector* Monitoring the Watershed**

The *ForestProtector* monitors the forest area in the *Watershed* and can observe the whole watershed to find new *LandusePlots*. If the number of new *LandusePlots* exceeds the threshold set in the *Parameters* (default = 8), the *ForestProtector* will convey this information to the *VillageNetwork*.

5.2.6.9 *VillageNetwork* function

The *VillageNetwork* sets up a committee meeting every month, though each member *Farmer* may be absent from the meeting based upon the *chanceAbsentMeeting* attribute of the *Parameters*. There are two possible subjects that each member can brings to the *VillageNetwork* meeting: the water deficit problem and/or the finding of a new *LandusePlot*, as the result of water observation and/or information dissemination processes, and also a report from the *ForestProtector*. In the meeting, the number of attending committee members must be at least half of the total registered committee members in order to consider such a case.

For the water deficit problem, the possibility that the committee will consider the case is 50percent. In order to solve this problem, the amount of water used by each *Farmer* should be limited by specifying the size of the irrigation water pipe, where the size determines the amount of water units allowed. For the debating process to regulate the water pipe size, if there is no rule in existence, the committee will specify a limited pipe size of five, which refers to the maximum number *LandusePlot(s)* on which each *Farmer* can cultivate crops. This limiting of the water pipe size rule then becomes effective in the following time steps. If a rule already exists, the regulated pipe size will be reduced by one. The default range of alternative pipe size specified in the *Parameters* is between two and five, thus when the rule is implemented, the maximum water amount each *Farmer* is allowed to use is between two to five units. This will become effective in the *Farmer planWaterAmount* process.

Each new *LandusePlot* reported case is debated, and the result is based on the number of votes. For the decision process, each committee member gives a vote in support of a *Farmer* that belongs to his village, or a *Farmer* from the same ethnic group. Support means allowing the owner of the reported case to continue using the plot, otherwise the new plot should be withdrawn and the owner punished. If the vote goes for withdrawing the plot, the member who represents the new *LandusePlot* owner's village will contact him/her and negotiate. The chance of succeeding in this task is based on the *chance2MeetNewPlotOwner* attribute, as determined by the *Parameters*. In case that the new *LandusePlot* owner is poor (the cash income balance is negative and the owner holds only two *LandusePlots)*, the new *LandusePlot* will not be withdrawn. Otherwise, the *Farmer* who opened the new *LandusePlot* is fined an amount of 3,000 baht (as announced by the Maehae village network committee); the new *LandusePlot* is withdrawn and re-forested, and the owner will be sanctioned and barred from creating a new *LandusePlot* within the sanction period, as specified in the *Parameters*.

5.2.7 Model Initialization

The spatial setting of the MHM is composed of 135 x 106 square cells (*LandUnit*) as initialized from the Cormas ENV file, and this provides the visual interface that represents the Maehae system. The data structure of the ENV file covers the attributes and values of the *LandUnit* entity, which are *landCover*, owner and slope.

During the initialization, the *LandusePlot* is aggregated from the adjacent *LandUnits* with the same *landCover* value specified for agricultural land, and then aggregated into the *Farm* using the owner code number. Thus, after initialization, there will be a number of *Farms* equal to the number of *Farmers*, as each of them is owned by a Farmer. The other land cover types aggregated into spatial features are the forest, roads and streams. Figure 5.8 shows the spatial setting with the aggregated entities; the upper and the lower parts represent upstream and downstream areas respectively. The *LadusePlots* in a farm are located in different locations. This spatial configuration, the number of *Farms* (ten farms) and *LandusePlot*(s) (57 plots) correspond to the role-playing game design for land-forest management.

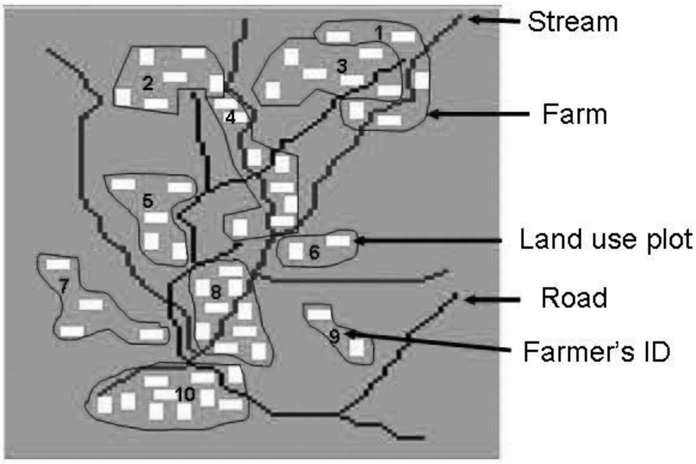


Figure 5.8: The Cormas spatial grid represents the spatial setting of the MHM

There are ten *Farmers* in the model, each of them posses one *Farm* with different numbers of *LandusePlot(s)*; they belong to either the Karen or Hmong ethnic group, and to three villages. Each *Farmer* has kinship ties with one other farmer, and some of them are social leaders, meaning they are a committee member of the *VillageNetwork*; thus, in the MHM, the *VillageNetwork* is composed of four members, with two members each from the Hmong and Karen ethnic groups. The *Farmers* are initiated with three different economic statuses, thus there are differences in their initial capital and monthly consumption costs. The *Farmers*' profiles are provided in Table 5.10.

Table 5.10: The *Famer* agents' initial attributes profile

Farmer id	Village	Initial Capital	Ethnicity	Relative	Social Leader?	Monthly Consumption Cost	# of Farm Plot
F10	1	20,000	H	F4	yes	2,500	5
F8	1	20,000	H	F6	no	2,500	6
F4	1	20,000	H	F3	no	2,500	6
F2	2	10,000	H	F5	no	2,500	8
F3	2	10,000	H	F3	yes	2,500	5
F1	2	10,000	K	F8	yes	2,000	2
F5	2	10,000	K	F9	no	2,000	4
F7	3	5,000	K	F10	yes	2,000	9
F6	3	5,000	K	F1	no	2,000	2
F9	3	5,000	K	F2	no	2,000	10

Note: H = Hmong, K = Karen

The initial setting of the Farmers' profile covers the heterogeneities of farmers across multiple villages, economic statuses, ethnicities and agricultural land holding size. The minimum initial capital provided allows for the investment in two farm plots, with the monthly consumption cost based on the cash expenses for food obtained from the field survey (LDD survey); the number of farm plots is derived from the land use survey data carried out by the LDD in 2003 (LDD survey).

Every initialization provides the same spatial setting and agent profile. The simulation run starts in the first month of the year (January), the season periods are based on the three common seasons in Thailand (hot, wet and cold). The maximum number of time steps is 96 steps (eight years).

5.2.8 Inputs

The cold, hot and wet seasons cover the periods November to February, March to June and July to October respectively. Rainfall amounts are randomly given during the wet season, and this determines and updates the amount of *waterMonthlyReleased* and storage of *Water*. Crop input data (price, investment costs, harvesting time and yield) are varied on a monthly basis. Examples of crop prices, investment costs, harvesting periods and the average yield for each month and season are shown in Table 5.11.

Table 5.11: Examples of low (L), medium (M) and high (H) crop prices (per kg) and investment costs (Thai Baht*) for Lettuce

Season	Month	Price (L)	Price (M)	Price (H)	Cost per 1,600 m2	Harvesting Age (month)	Average Yield kg/1,600 m2
Cold	Jan	3.0	3.5	4.0	5,000	2	1,825
	Feb	3.0	4.0	5.0			
Hot	Mar	8.0	9.0	10.0	8,000	2	1,848
	Apr	15.0	15.0	5.0			
	May	20.0	20.0	20.0			
	Jun	20.0	20.0	20.0			
Wet	Jul	10.0	15.0	20.0	4,500	2	1,080
	Aug	8.0	9.0	10.0			
	Sep	8.0	14.0	20.0			
	Oct	20.0	20.0	20.0			
Cold	Nov	15.0	17.5	20.0	5,000	2	1,825
	Dec	4.0	4.5	5.0			

* 1 Thai Baht = 0.027 $US.

5.2.9 Simulation - Observed Indicators

To interpret the simulation output that reflects agricultural production, economic revenue and the availability of land, forest and water resources, as the objectives of the MHMs development and use, the output indicators resulting from model simulation can be observed at the local level (low-level state variable) and the global level (deduced from the low-level variable). The global indicators give the overall properties of the modeled system, revealing the status of watershed resources (water availability, forest area and forest encroachment), agricultural production performance (cultivated area and crop failures), and the economic return which is the total cash income balance. The local indicators detail the performance of each individual *Farmer*, and include cultivated area, crop failure and cash income balance. These indicators, observed from the simulation results, can be used for analysis and for comparing simulation results across different scenarios (Table 5.12).

Table 5.12 The observed indicators from the MHM simulation.

Level of observation and indicators	description
Global	
cultivated plot	number of cultivated LandusePlot
crop failure plot	number of crop failure LandusePlot due to deficit water supply
new plot created	number of new LandusePlot created
new plot found	number of new LandusePlot found by the Farmers
new plot reclaimed	number of new LandusePlot withdrawn as the result from the VillageNetwork meeting
total cash	total cash income of all the farmers
pipe size	limited pipe size as the result of water rule implementation
Local	
income	the farmer's cash income

5.3 Model Simulation and Scenario Test

The MHM model is tested using four scenarios, which are: *first-come first-served*, *equal water sharing*, *business as usual* and *limiting pipe size*. The first scenario aims to explore only water management, to test the Farmer's crop allocation and water balance processes. The second scenario seeks to test the fitness of water demand and supply, where each Farmer receives an equal amount of total available water and where there is neither the creation of a new *LandusePlot* nor intervention from the *ForestProtector* or the *VillageNetwork*. The third scenario is used to represent the actual practices of the farmers in Maehae. The fourth scenario tries to reproduce the emergence of a water rule through the roles of individual *Farmer*, the *ForestProtector* and the *VillageNetwork*.

5.3.1 Scenarios

5.3.1.1 'First-come first-served'

This scenario represents the regulation implemented in the water management RPG and the actual water use practices in Maehae. The processes involve farm management, without creating a water rule or a new farm plot. The upstream area *LandusePlot* receives the water supply before the downstream area *LandusePlot*. The *Farmer* has experienced a water shortage problem more than two consecutive times, and he again faces a dry season, thus reduces the number of his cultivated *LandusePlot(s)* to avoid the risk. This scenario attempts to show how this would affect farm and watershed performance without intervention from the *ForestProtector* and the *VillageNetwork*.

5.3.1.2 'Equal water sharing'

The scenario imitates the management behavior suggested by the water RPG players, and was the management scheme regularly proposed by members of the village network committee during the field investigations. The level of equal water shared is determined at the model level, for each time step, after the *Water* storage has been updated, and the shared water amount is equal to the *Water* storage divided by the number of the *Farmers*. The *Farmers planWaterAmount* subsequently corresponds to this shared water, and the *Farmers* cultivate a number of *LandusePlot(s)* that corresponds to the amount of water.

5.3.1.3 'Business as usual'

The 'business as usual' scenario illustrates the actual local land-forest management practices. The *Farmers* use water based on the principle of the 'first-come first-served' rule; however, the one who faces water a shortage problem may seek a new *LandusePlot* in the upstream area, in order to maintain *Farm* production. The *VillageNetwork* is activated and sets up a monthly meeting to consider the new *LandusePlot* case that may occur. This is the standard configuration of the MHM model; it involves all the roles of the *Farmer, ForestProtector* and the *VillageNetwork*; the *Farmer* may create a new *LandusePlot* and there is no rule proposing to limit the water pipe's size.

5.3.1.4 'Limiting pipe size

The 'limiting pipe size' scenario represents the emergence and evolution of a rule as a result of both individual *Farmer* and collective action through the *VillageNetwork* function. The scenarios aims to reproduce the recent agreement on limiting the size of the water pipe size, an agreement made between water users in the upstream and downstream areas of Maehae watershed. The 'limiting pipe size' scenario simulation follows the full process and scheduling of the MHM, as described in the model description section. All agents are active, establishing new *LandusePlot(s)* and water rule propositions on limiting the size of the pipe.

5.3.2 Simulation Results

Each proposed scenario is simulated ten times, with 96 simulation steps. The simulation output analysis is carried out to reveal temporal and performance changes on agricultural production, economic revenue and the environmental resources of the modeled system. The agricultural production is determine by the number of *LandusePlot(s)* that are cultivated and the failure or success of the harvest due to water availability; thus the number of crop failure plots can be used to express the water balance. The cash income balance at the end of the simulation is used to reflect the difference in economic returns among the scenarios. The environmental resources are water balance and land utilization; the water balance is compared across all scenarios, while changes in land utilization occur only in the last two scenarios, when the *LandusePlot* can be created or withdrawn. Thus, these two indicators determine the disturbances in and stability of the watershed resources. Some of these indicators can then be analyzed and compared to each other at the individual, whole system, or individual/whole system levels. In the 'limiting pipe size' scenario, the 'pipe size' indicator is observed to see the emergence of a water use rule by limiting the water pipe size.

5.3.2.1 Failure and Success of Crop Cultivation

The total number of cultivated, failed and successful plots is compared. Both the cultivated plots and failed plots are highest in the 'business as usual' scenario, and lowest in the 'equal water sharing' scenario, but the percentage success of the 'equal water sharing' and the 'limiting pipe size' scenarios is higher than the other two. The result is similar when focused only on the dry season, when water is limited and causes most of the crop failures. The results are shown in Table 5.13.

Table 5.13: Level of failure and success of the cultivated *LandusePlot*

Scenario	Cultivated	Failed	Success	Success%
All Seasons				
First-come, first-served	2,961	465	2,496	84.31
Equal water sharing	2,408	26	2,383	98.94
Business as usual	3,063	507	2,556	83.44
Limiting pipe size	2,637	246	2,391	90.69
Dry Season				
First-come, first-served	1,625	454	1,171	72.06
Equal water sharing	1,384	23	1,361	98.34
Business as usual	1,638	492	1,146	69.96
Limiting pipe size	1,102	246	856	77.68

The number of cultivated plots and crop failure plots is shown in Figure 5.9 and Figure 5.10.

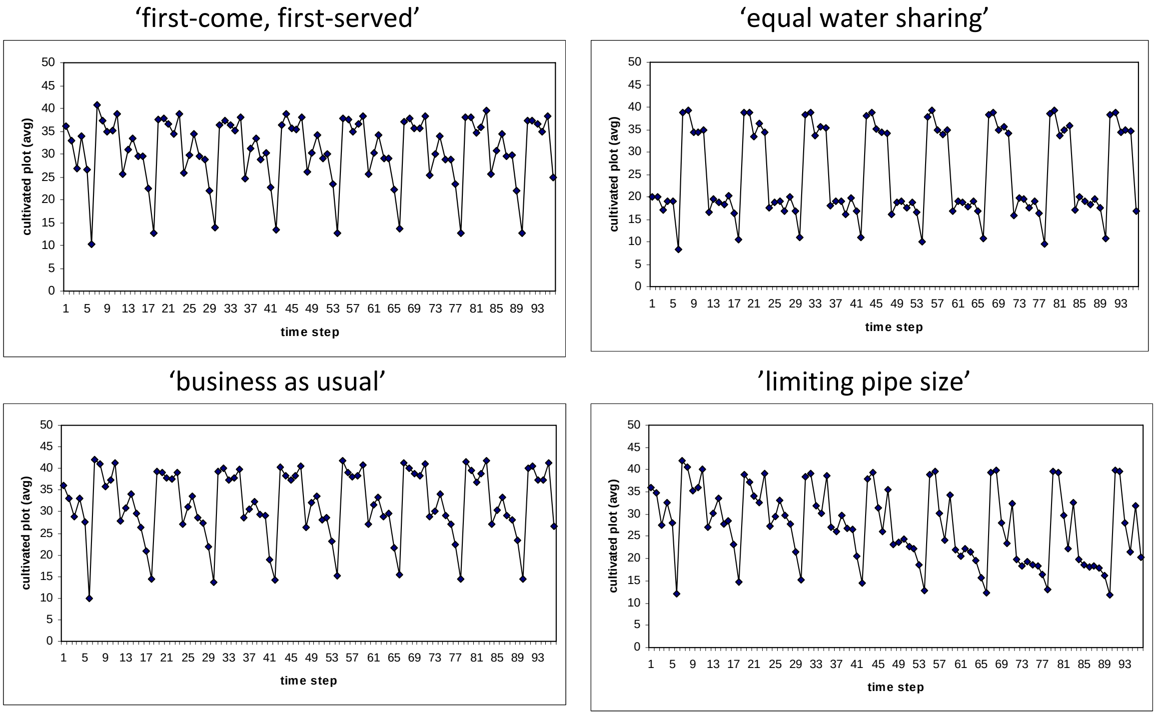


Figure 5.9: Crop cultivated plots; average of 10 runs

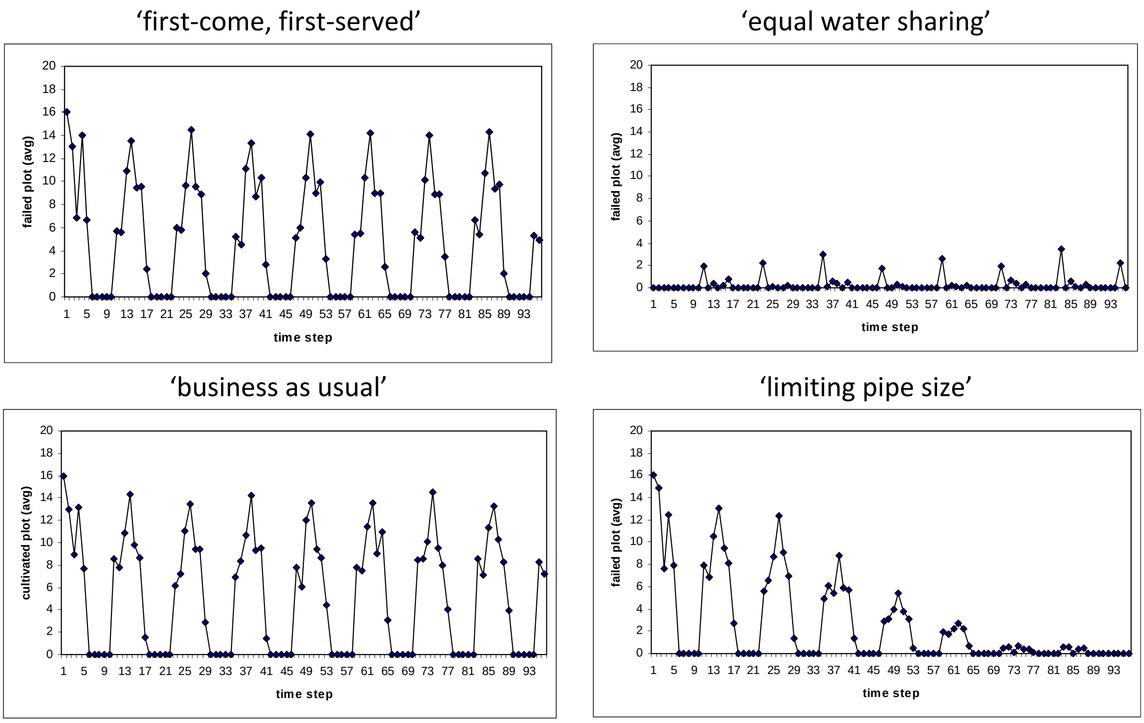


Figure 5.10: Number of crop failure plots; average of 10 runs

Most of the crop failures occur during the dry season, Figure 5.11 shows the average number of monthly cultivated plots in the dry season. Figure 5.12 reveals temporal changes in terms of crop failure plots per year, during the 96 time step simulation (eight years). The 'limiting pipe size' gives a declining curve, the number drops from 60 at the beginning to two at the end; while the curves are fairly stable under the other scenarios.

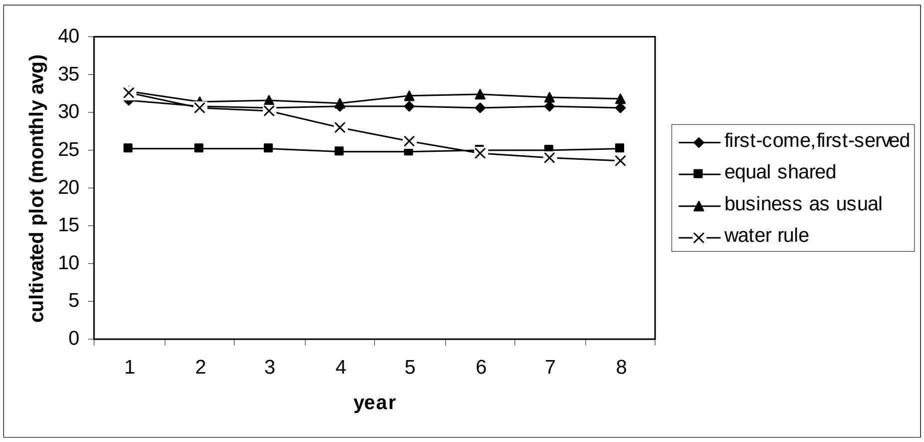


Figure 5.11: Crop cultivated plots during the dry season; average of 10 runs and a comparison among 4 scenarios

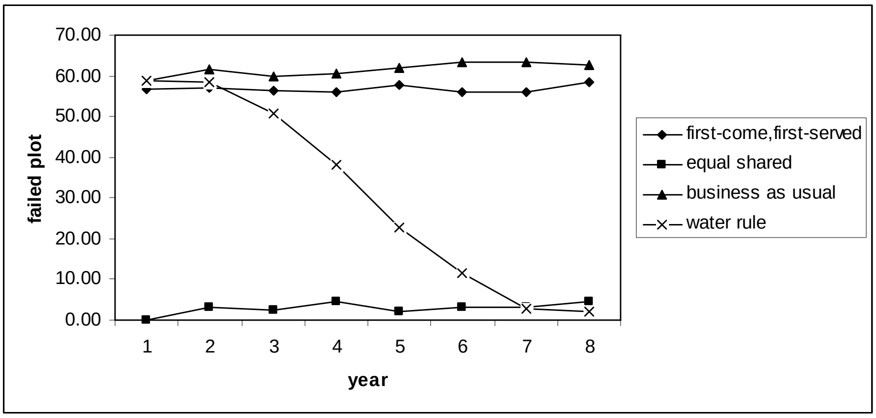


Figure 5.12: Number of crop failed plots per year

The level of success of cultivated plots during the dry season is shown in Figure 5.13.

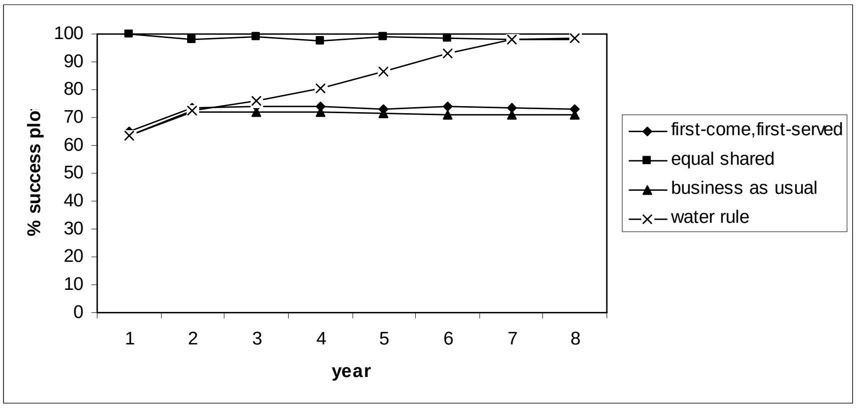


Figure 5.13: Percentage success of plots during the dry season, per year; comparison among 4 scenarios

5.3.2.1 Cash Income

The cash income from selling agricultural products is analyzed at both the individual and global levels. At the global level, total cash income is used to compare the economic revenue among scenarios; and gini coefficients are analyzed to reveal the distribution of the income. Table 5.14 shows the total cash income comparison. The 'equal water sharing' scenario gives the highest total cash income, and the second is the 'limiting pipe size' scenario. In summary, the total cash income is low and very low in the 'first-come, first-served' and the 'business as usual' scenarios respectively.

Table 5.14: Average individual cash income balance; 10 runs

Farmer	first-come, first-served	equal water sharing	business as usual	limiting pipe size
1	332933.70	229143.70	323590.70	244870.30
2	388047.30	283502.20	377531.40	277108.40
3	401026.60	286922.00	389657.60	286166.40
4	427566.70	265336.40	250641.60	295697.10
5	300339.30	232035.00	-48489.80	224828.15
6	66599.77	149589.80	-92689.53	80236.80
7	-337955.30	177454.80	-335398.40	26812.87
8	-233701.90	260413.20	-278216.85	-37076.53
9	-251477.80	130477.95	-194421.20	-87631.42
10	-508067.30	188435.20	-325778.10	-161884.70
Total	585,311.07	2,203,310.25	66,427.43	1,149,127.37
Avg	58,531.11	220,331.03	6,642.74	114,912.74
Min	-508,067.30	130,477.95	-335,398.40	-161,884.70
Max	427,566.70	286,922.00	389,657.60	295,697.10
STD	358,336.48	55,981.42	299,299.96	172,238.31

Table 5.15 shows the gini coefficient analysis results of the four scenarios. In general, a gini coefficient value equal to or below 0.4 means the income distribution is equitable. Thus, the simulation results reveal that the increased income amount in all scenarios compared to the worst case (‘business as usual’), is equally distributed among all farmers.

Table 5.15: Gini coefficient comparison among four basic scenarios; 10 runs

Scenario	Mean	Min	Max	STD
First-come, first-served	0.332	0.318	0.360	0.013
Equal water sharing	0.094	0.076	0.112	0.012
Business as usual	0.405	0.297	0.487	0.056
Limiting pipe size	0.313	0.237	0.383	0.047

The differences in cash income between the ‘first-come, first-served’ scenario and the others are shown in Table 5.16. The farmers (1 to 5) whose plots mostly are in upstream and mid-stream locations lose cash income, while the others (6 to 10) gain a greater income, except for the ‘business as usual’ scenario; the most occurs in the ‘equal water sharing’ and the ‘limiting pipe size’ scenarios.

Table 5.16: Cash differences between the ‘first-come, first-served’ and the other scenarios

Farmer	with ‘equal water sharing’	with ‘business as usual’	with ‘limiting pipe size’
1	-103,790	-9,343	-88,063
2	-104,545	-10,516	-110,939
3	-114,105	-11,369	-114,860
4	-162,230	-176,925	-131,870
5	-68,304	-348,829	-75,511
6	82,990	-159,289	13,637
7	515,410	2,557	364,768
8	494,115	-44,515	196,625
9	381,956	57,057	163,846
10	696,503	182,289	346,183

The individual cash income gained during the simulation can be observed and compared across the three scenarios, as shown in Figure 5.14.

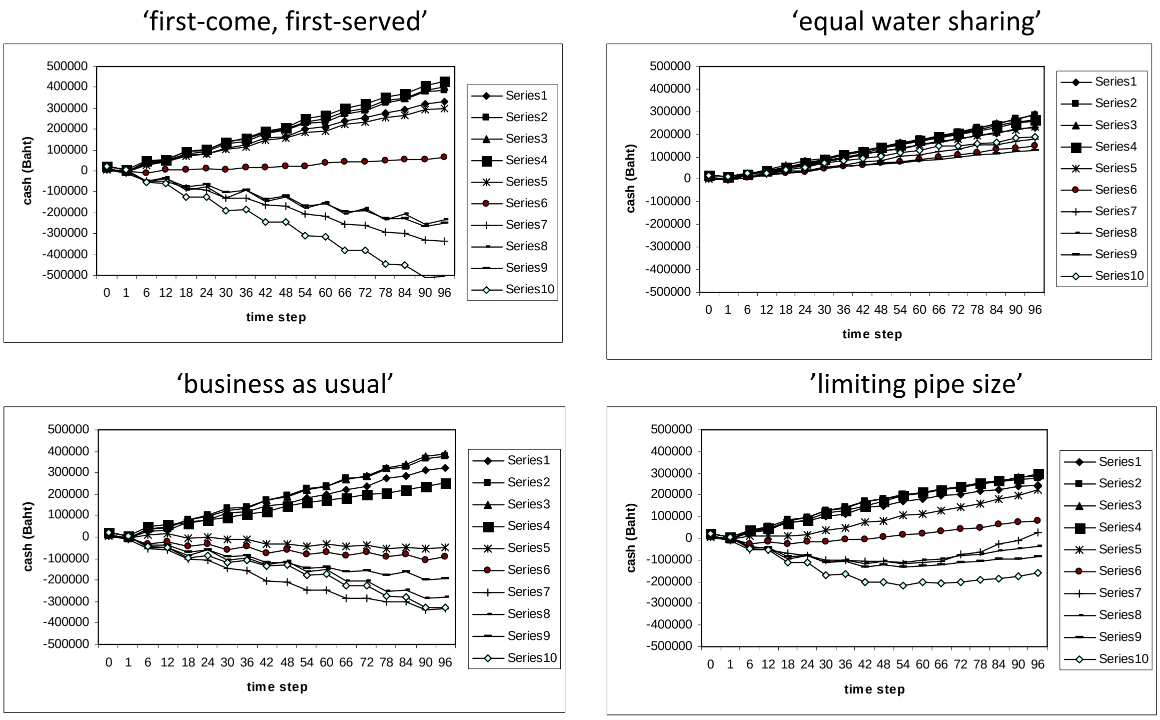


Figure 5.14: Comparison of individual cash income balances among the four scenarios; 10 simulations.

5.3.2.1 Resource Dynamics

The water balance of the four scenarios is illustrated in Figure 5.15. A water deficit occurs during the dry season in the ‘first-come, first-served’ and ‘business as usual’ scenarios; this pattern stands through the simulation steps, but does not occur in the ‘equal water sharing’ scenario, where the water availability is well balanced. The ‘limiting pipe size’ scenario reveals a gradual rise in the water balance; a water deficit occurs at the beginning and approaches a balance toward the end of the simulation.

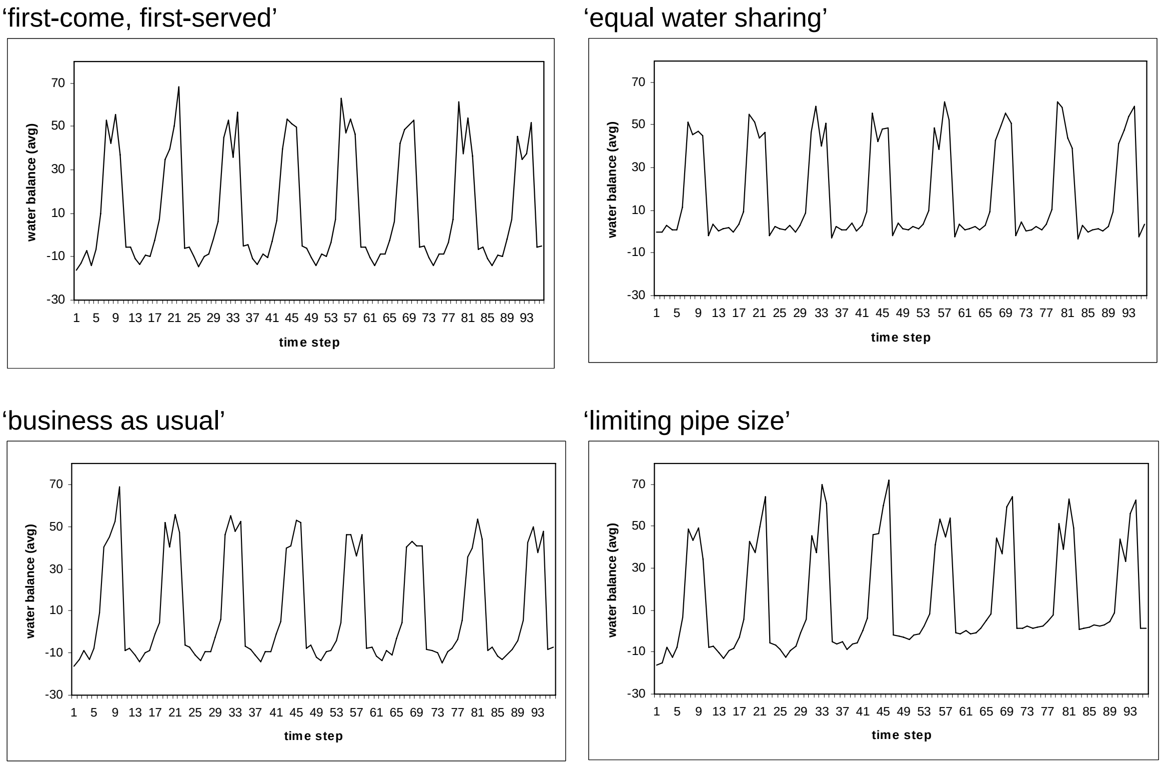


Figure 5.15: The water balance, among four scenarios; 10 simulations

The water balance change in the 'limiting pipe size' scenario corresponds to the emergence of the water rule, one that can be observed as a limited 'pipe size', which occurs during the simulation, as shown in Figure 5.16.

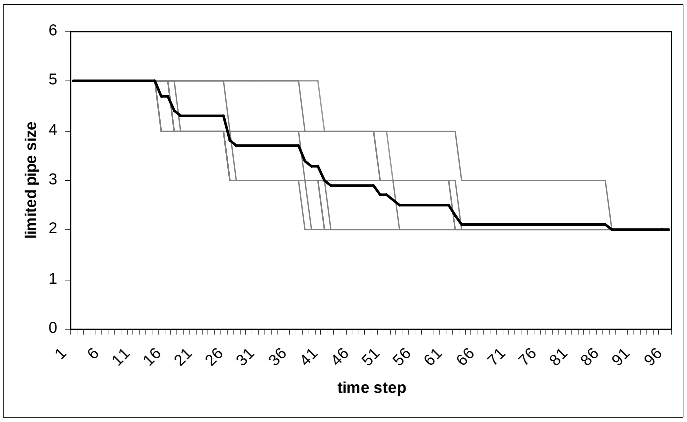


Figure 5.16: Changes in water pipe size resulting from the 'limiting pipe size'; the thick curve is the average of 10 simulation runs

Dynamics of the *LandusePlot* can be observed from the 'business as usual' and 'limiting pipe size' scenarios, the total number of new plots is 61 and 17 respectively. It can be seen that that the water-use rule (limiting the size of the water pipe) affects a decrease in the establishment of new *LandusePlot*, or on the other hand, forest encroachment.

5.3.3 Simulation Results: Interpretation and Discussion

Under the ‘first-come first-served’ rule, an upstream farmer has better access to the water. The limited amount of available water is taken by cultivated plots in the upstream areas, thus a water shortage occurs every dry season when total water demand exceeds the supply and the available water is far below the balance point. After experiencing a water shortage, the downstream farmer tries to reduce the number of cultivated plots. The adaptive farm management process is implemented at the individual level; however, this cannot cope with the problem within a dry period (over eight months). When the wet season arrives, the farmer increases the level of cultivation, and will face a water shortage problem again in the next dry season. The number of crop failure plots is somewhat consistent through all the simulations; there are three groups of *Farmers* who have high, low and negative cash income balances, as the results show in Table 5.14. However, the gini coefficient shows an equality of income distribution.

The ideal ’equal water sharing’ scenario simulation seems to be the best for resolving the water shortage problem. The given amount of water determines the crop allocation in this scenario. The water amount is in excess during the rainy season, and the amount of shared water available during the dry season is equal to two, thus a farmer can cultivate two plots as a maximum. Some crop failures occur immediately following the end of the rainy season because farmers cultivate more plots during the rainy season and cannot harvest them in time. This ideal water management system can overcome the water shortage problem instantly, since the overall number of cultivated plots is determined by the water available. The cash income balance increases with every time step and the distribution of income is homogenous, as expected. The equality of income distribution, as determined by the gini coefficient, is the highest among all, thus this is the best scenario in terms of equal distribution of income.

The ‘business as usual’ simulation does not solve the water shortage problem but rather distributes the problem; one who tries to solve his problem by creating new plots in the upstream then passes the problem on to others. This is why the upstream individuals earn less from this scenario; although the downstream farmers gain more income, they still cannot produce enough crops and most of their cash income balances are negative. It can be seen that the number of crop failure plots and total cash income are even worse than in the ‘first-come first-served’ scenario, from an economic point of view. This is because downstream farmers cultivate more by creating new farm plots, while the water supply does not vary. The farmers whose farms are located in the downstream area create new plots in the upstream areas when they face a crop failure problem, thus the total number of cultivated plots increases, while the water supply is more or less adequate, as per the ‘first-come first-served’ scenario; however, when more water is taken by the new upstream farm plots, their farm plots and priorities in accessing the water are re-ordered, leading to a reduced water supply, and thus the total cash income of the upstream farmers (#1 to #5) decrease while the downstream farmers gain more income; however this does not solve the water shortage problem in the downstream areas - the cash income balances are still negative and the inequality in terms of income distribution is higher than in the other scenarios.

In the 'limiting pipe size' scenario simulation, the downstream farmers who face water shortages try to adapt their farm management practices by reducing the number of cultivated plots during the dry season. If the problem still exists and occur on more than two consecutive occasions, the farmers will raise the water shortage problem with the village network committee, and after meeting and justifying their actions, the village network will release a limited pipe size rule (ranging from two to five), applying for all farmers. Simulation result shows that the farmers gradually reduce their pipe size, and the number of cultivated and crop failure plots during the dry season decreases continuously within 65 time steps, then is almost stable towards the end. Farmers #6 and #7 have positive cash income balances at the end of the simulation. Although the rest of the downstream farmers still have a negative cash income balance, the trend curve is moving toward the positive region and an equality of income distribution can be observed.

The 'equal water sharing' scenario is a kind of top-down resource management approach: the regulation could be imposed by technical expert's knowledge or by policy, and might usually be difficult to bring into practice. This idea was regularly proposed during the focus group workshops and the village network meetings, but never came into practice due to various obstacles, as described earlier.

The simulation results show that the 'business as usual' scenario is not efficient in terms of crop failures, and it segregates further the distribution of income, as is also observed in reality. New farm plots exist in the upper part of the watershed and the water deficit remains in the lower part. During the dry season in Maehae, farmers abandon the downstream farm plots where there is a deficit of water. The encroachment into the upper parts slightly improves the income of the poorest farmers, but it disseminates the problem to farmers who were previously receiving the correct amount of water and who now face water shortages. The poorest do not solve their problem and some new farmers face difficulties, as in reality.

The 'limiting pipe size' scenario simulation reveals a gradual decrease in the number of crop failure plots. This scenario eliminates the water shortage problem within 65 simulation steps; after this point the model behaves similarly to the 'equal share of water' simulation. This scenario reveals that the water regulation can resolve the water shortage problem, not immediately but in the long run, through the farmers' adaptation processes.

The scenario simulations give an interesting and acceptable result, reflecting the roles and interaction between individuals and the collective action when intervening in land, forest and water management, and the dynamics. The 'first-come, first-served' and 'equal water sharing' scenarios are a theoretical exploration to explain 'what if' the water resource was solely managed or ideally managed, without intervention from individual and collective agents. The ‘business as usual’ scenario represents the actual resource management situation. One interesting result from the ‘limiting pipe size’ scenario reflects the wishes of one MH stakeholder and has become a water management rule recently agreed upon among upstream and downstream water users. The rule is initiated by an individual *Farmer* whose crop failure occurs as consequence of the other *Farmers’* decision-making and action, and also the intervention of the *VillageNetwork,* which are determined by stochastic functions as well as the parameters set for each sub-process. At this stage, it cannot be pin-pointed and assessed as to which of these determinants factors contributes, or to what degree, to the interested system properties. This leads to further questions and scenario simulation exploration on the effects and sensitivity of the contributing factors applied in the model, and influences the changes and performance at the individual and whole system level regarding resource availability, economic revenue and farm production. Moreover, this should provide an explanation as to how these contribute to equitability, which is considered an important criteria for the sustainability of the system.

5.4 Simulation on Individual and Collective Resource Management

In the previous section, the four scenarios illustrate how the ideal and actual land, forest and water resource management strategies affect the performance of the whole watershed and the farmers. Those are the results from only one set of model parameters used with the main roles of individual and group agents in the model contributing to the simulation results which cover monitoring, information dissemination, the Village Network meeting and farm management. Furthermore, some of the parameters are randomly chosen, and are different from one run to another, thus the results cannot be tested for consistency nor be compared among scenarios. The next question is: how does each of these roles contribute to the performance of the modeled system? To answer this, a set of scenarios have been developed, varying the parameters and functions used in the decision making process of the major roles of *Farmer* and *VillageNetwork;* and the focus is put on the ‘business as usual’ and ‘limiting pipe size’ scenarios. These two scenarios will be explored and analyzed for sensitivity of the relevant parameters.

The parameter related to the monitoring role of the *Farmer* is the observation range; three ranges are set to represent three different levels of watershed monitoring. This parameter is also applied when the *Farmer* looks at a neighboring farm in order to disseminate information on the new *LandusePlot(s)* found as a result of the monitoring. There is an assumption that social relationships may affect information dissemination and the later consequences, thus the scenarios cover options that take into account the existence of a social network. Another important role of the *Farmer* is decision-making on solving the water deficit problem, either by creating a new *LandusePlot* or reporting the problem to the social leader and conveying a message to the *VillageNetwork* for consideration, and to take action.

The ability of the *VillageNetwork* to take action or to make a decision on new farm plots or the water deficit problem depends upon several factors and circumstances that can be observed during monthly meetings. In the simulation, some of the committee members are absent from the meetings, and the committee cannot consider a case if the number of members attending is not sufficient. When the committee considers a new plot case, after a long debate without a unanimous agreement the committee proposes a vote, and each member tends to support new plot owners who have the same ethnicity; therefore, the *VillageNetwork* may either vote against the case, in which case the new plot owner must stop cultivating, or votes to attenuate the case, in which case the owner can resume with cultivating the plot. Although the vote may go towards withdrawing the plot, the new plot owner may refuse to follow the sentence. If the new plot owner complies with the judgment of the *VillageNetwork*, then the penalty and sanctions are applied. Thus, those factors that contribute to the functioning of the *VillageNetwork* are levels of absenteeism from the monthly meetings, lobbying (for votes), success in withdrawing the new plots and the sanction period.

5.4.1 Factors and Parameters Set

The scenarios with respect to influences of the monitoring (individual concern) and the functioning of the *VillageNetwork* (institutional performance) on farm production, economic values and the watershed resources of the MHM, are combinations of the five factors and the parameters detailed in Table 5.17. Thus, there are 48 sub-scenarios (simulation configurations) which are a combination of the five factors for each main scenario.

Table 5.17: Parameter setting of the five factors applied for sensitivity analysis

Factors	Parameters Settings
Social Network (Soc)	True/False
Lobbying (Lob)	True/False
Sanction Period (San)	None, 12 months, forever
Monitoring (Mon)	1. Weak: observation range = 15 cells
	2. Strong: observation range = 30 cells
VillageNetwork Functioning (VN)	1. Weak:
	Chance of absenteeism of the member = 0.3
	Chance of vote against the new plot case = 0.7
	Change of success in withdrawing the new plot = 0.3
	2. Strong:
	Chance of absenteeism of the member = 0.1
	Chance of vote against the new plot case = 0.9
	Change of success in withdrawing the new plot = 0.8

5.4.2 Scenario Description and Simulation Set

There are two main scenarios developed for exploring the contribution of the five factors explained above. Sequences of events and agent roles correspond to the 'business as usual' and 'limiting pipe size' scenarios. The following are the scenario descriptions that determine the specific processes, where the variations of the determinant factors are set.

5.4.2.1 'Business as usual'

- The *Farmers* monitor the new *LandusePlot* within the observation range set.
- If the social network exists (true), the farmers disseminate the new plot found information to the neighboring farm's owner, whose farm is located within the observation range, as well as their relatives and their village leader (including the village network committee), but ignore the case of their own relatives and their own village leaders. If the social network does not exist, all the cases are reported to the social leader.
- The *Farmer* who faces a water deficit problem (experienced problem => 3 times), whose farm size < 3 plots, and cash income is negative, may create a new plot in an upstream area (50percent probability).
- At the village network meeting, the case(s) will be reported to the committee; committee members may be absent from the meeting; this depends on the percentage of absenteeism.
- The committee will vote for the case. The result can be:
  - If there is lobbying, the vote will be determined by the proportion of Hmong and Karen committee members (majority will support the new plot owner who has the same ethnicity).
  - If there is no lobbying, all the member will vote against the new plot owner, chance is varied by the strength of the *VillageNetwork* functioning.
- If the vote result goes to withdrawing the new plot and sanctioning the owner, the representative committee member will carry out the task. The chance of success depends on the percentage of those withdrawing the new plot. If this succeeds, the sanction period will be applied to the new plot owner (this means he/she will be able to create a new plot again after this sanction period.
- The *Farmer* who faces a water deficit problem (experienced problem => 3 times), whose farm size < 3 plots, and cash income balance is negative, will create a new *LandusePlot* in the upstream area, while the others *may* create new plots in the upstream area (50percent probability).

5.4.2.2 ‘Limiting pipe size’

- The *Farmers* monitoring and disseminating information roles are the same as described in the ‘business as usual’ scenario.
- The *Farmer* who experiences a water deficit problem more than two times will propose a rule to limit the pipe size (no matter whether the *Farmer* has been sanctioned or not). In addition, if the *Farmer* is not being sanctioned, he/she may create a new plot in the upstream area using rules and conditions explained in the general model description.
- At the village network meeting, there will be possible cases brought to the debate, which will be related to a water deficit problem or a new plot being found.
  - For the new plot found case, the process is the same as described above in the ‘business as usual’ section.
  - For the water deficit case, the *VillageNetwork* may issue a water use regulation by limiting the pipe size (in the range five to one). This rule will be applied to all the farmers in the following time steps. The regulated irrigation pipe size determines the maximum amount of water that each farmer can obtain.

Each of the 48 sub-scenarios is simulated over 96 time steps, with ten repetitions.

5.4.3 Scenario Simulation Data Analysis

The simulation data is primarily analyzed using descriptive statistic and analysis of variance (ANOVA) methods to analyze the effects of the five fixed qualitative independent factors on some dependent indicators. These indicators are total cash, equality of income distribution (gini analysis), crop failure plot, new plot created, new plot found, new plot reclaimed and efficiency of water rule emergence. The abbreviations of the five factors used in this analysis are:

- Soc = social network (1 = false, 2 = true)
- Lob = lobby (1 = false, 2 = true)
- San = sanction period (1 = none, 2 = 12 months, 3 = forever)
- Mon = monitoring level (1 = weak, 2 = strong)
- VN = Level of the VillageNetwork functioning (1 = weak, 2 = strong)

For each scenario simulation, the between-subject factors and the number of output data are structured as in Table 5.18. The data is analyzed using a univariate Analysis of the Variance of the SPSS statistical analysis software; a full factorial model is used to include all the main effects and all the interactions of the five determinant factors.

Table 5.18: The between-subject factors

Between-Subject Factors

		N
Soc	1	240
	2	240
Lob	1	240
	2	240
San	1	160
	2	160
	3	160
Mon	1	240
	2	240
VN	1	240
	2	240

5.4.3.1 Total Cash income and Income Distribution

The total cash income of all the farmers is analyzed to compare the economic outcomes of the system between the two scenarios.

Regarding the effects of the main factors, the standardized coefficients in Table 5.19 and Figure 5.17 explain that the sanction period is the only factor that significantly determines the cash income, whereas lobbying, the sanction period and the discussions of the village network co-determine the cash income. The sanction period contributes the most, while the village network has a negative correlation with cash income.

Table 5.19: The standardized coefficients of the five factors and cash income

Scenarios	Soc1	Soc2	Lob1	Lob2	San1	San2	San3	Mon1	Mon2	VN1	VN2
Business as usual	0.000	0.004	0.000	0.003	0.000	<u>0.546</u>	<u>0.895</u>	0.000	0.044	0.000	-0.049
Limiting pipe size	0.000	-0.006	0.000	<u>0.092</u>	0.000	<u>0.872</u>	<u>0.970</u>	0.000	0.015	0.000	<u>-0.072</u>

Note: The bold and underlined numbers are significant.

‘Business as usual’ ‘Limiting pipe size’

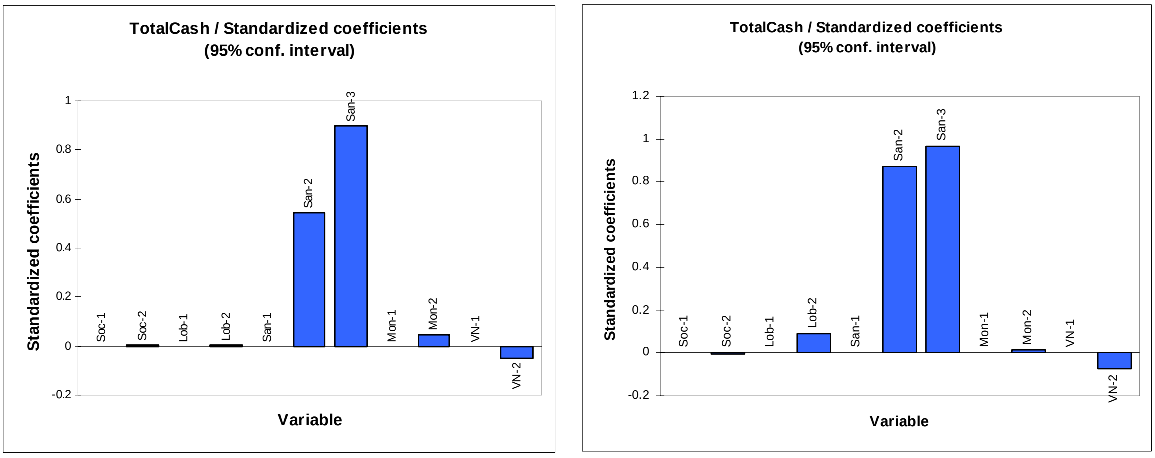


Figure 5.17: Standardized coefficients of total cash analysis between the two scenarios

The results of the test of between-subjects effects of the full factorial factors on the total cash income are shown in Appendix 1.1.1. The results show that, for the ‘business as usual’ scenario, the sanction period is the only factor that has a significant effect on the cash income. The between-subjects combinations that significantly determine the cash income are Lob*VN, San*Mon, San*VN and Mon*VN. The estimation marginal means in appendix 1.1.2 show the between-subjects of all five factors that contribute to the maximum and minimum cash income means, these being Soc2-Lob2-San3-Mon1-VN2 (632,002.25); and Soc1-Lob2-San1-Mon1-VN2 (-36,386.35) respectively (see the underlined and bold numbers).

The variance analysis results of the ‘limiting pipe size’ scenario simulation in Appendix 1.2.1 indicate that there are three main effects of Lob, San and VN in terms of contributing to the total cash income. The numbers of between-subjects effects that significantly determine the output variable are more diversified than in the ‘business as usual’ scenario. The maximum and minimum cash income means, as a result of the five factor combinations are: Soc1*Lob1*San3*Mon1*VN2 (1,270,517.39) and Soc1*Lob1*San1*Mon1*VN2 (-1,463,659) respectively (Appendix 1.2.2).

The sanction period is the main determinant in both scenarios; the longer the sanction period the higher the total economic value. In the ‘limiting pipe size’ scenario, the total cash income is the result of the distributed effects from many factors. The social network and monitoring level do not contribute to the total cash income.

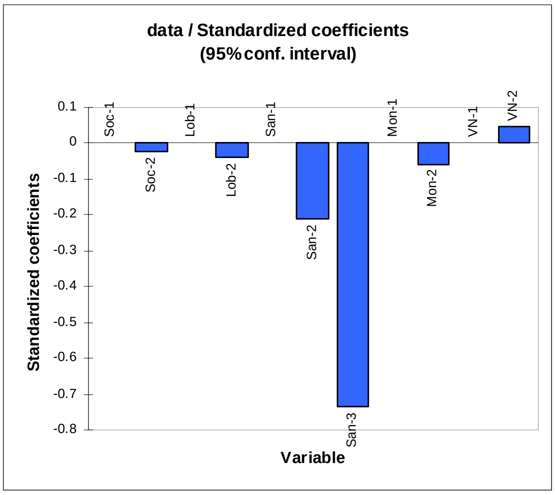
5.4.3.2 Cash Income Distribution

The gini coefficient analysis is used to assess the equality of income distribution. 480 gini values from all simulations are analyzed to explore its correlation with the five determinant factors. The results are similar to the previous cash income analysis in terms of determinant factors, but the correlations are reversed (Table 5.20 and Figure 5.18).

Table 5.20: The standardized coefficients of the five factors and gini coefficients

Scenarios	Soc1	Soc2	Lob1	Lob2	San1	San2	San3	Mon1	Mon2	VN1	VN2
Business as usual	0.000	-0.024	0.000	-0.039	0.000	-0.212	-0.734	0.000	-0.058	0.000	0.045
Limiting pipe size	0.000	0.025	0.000	-0.184	0.000	-0.694	-0.888	0.000	-0.040	0.000	-0.060

'Business as usual'



'Limiting pipe size'

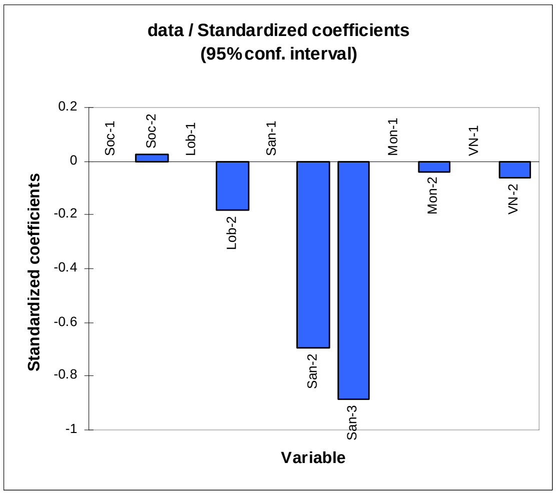


Figure 5.18: Standardized coefficients of the gini between the two scenarios

These results show that lobbying, the sanction period (main determinant) and the village network function are key factors that support the equality of income distribution. The imposition of sanctions is the only factor that significantly correlates to the gini in the 'business as usual' scenario.

For the 'business as usual' scenario, the between-subjects test of the full factorial factors effect on the gini value is shown in Appendix 1.1.3. There are not many between-subjects combinations that determine the gini significantly. The estimation marginal means in Appendix 1.1.4 show the between-subjects of all five factors that contribute to high and low means of income distribution equality, as follows: Soc2*Lob1(and 2)*San3-Mon1-VN1(and 2) (0.335); and Soc1-Lob2-San1-Mon1-VN1 (0.445) respectively.

The variance analysis result of the 'limiting pipe size' scenario simulation on the gini value shown in Appendix 1.2.3, depicts the three main effects that Lob, San and VN contribute to the simulation output. The numbers of between-subjects effects that significantly determine the output variable are more diverse than in the 'business as usual' scenario. The maximum and minimum gini values as are the result of the five factor combinations, as shown in Appendix 1.2.4, as follows: Soc2*Lob2*San3*Mon2*VN2 (0.298) and Soc2*Lob1*San1*Mon1*VN1 (0.517) respectively.

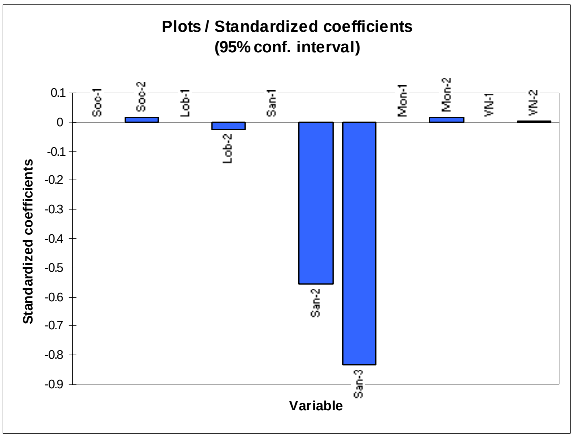
5.4.3.3 Crop Failure Plot

The contribution of the five factors to the number of crop failure plots is shown in Table 5.21 and Figure 5.19.

Table 5.21: The correlation test of crop failure plots

Scenarios	Soc1	Soc2	Lob1	Lob2	San1	San2	San3	Mon1	Mon2	VN1	VN2
Business as usual	0.000	0.015	0.000	-0.025	0.000	-0.556	-0.835	0.000	0.015	0.000	0.002
Limiting pipe size	0.000	0.029	0.000	-0.059	0.000	-0.565	-0.535	0.000	-0.009	0.000	-0.138

‘Business as usual’



‘Limiting pipe size’

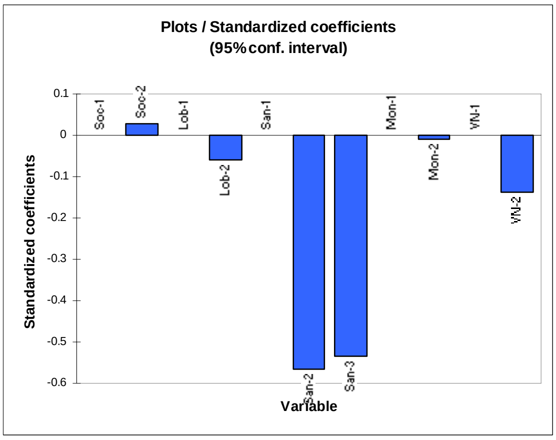


Figure 5.19: Standardized coefficients of the crop failure plots between the two scenarios

The main message of this result is that sanctions and village network functions lower overall agricultural production in the ‘business as usual’ scenario. The test of between-subjects effects shows that only sanctions have a significant effect on this indicator (Appendix 1.1.5). The maximum and minimum numbers of failed plots as a result of the five factor combinations are: Soc2*Lob1*San1*Mon1*VN1 (516.0) and Soc2*Lob2*San3*Mon1*VN1 (462.5) respectively (Appendix 1.1.6).

For the ‘limiting pipe size’ scenario, there are only two factors that significantly affect the crop failure plot, which are the sanction period and the village network function (Appendix 1.2.5). The maximum and minimum numbers of failed plots as a result of the five factor combinations are: Soc2*Lob2*San1*Mon1*VN1 (397.50) and Soc1*Lob1*San3*Mon1*VN1 (173.90) respectively (Appendix 1.2.6).

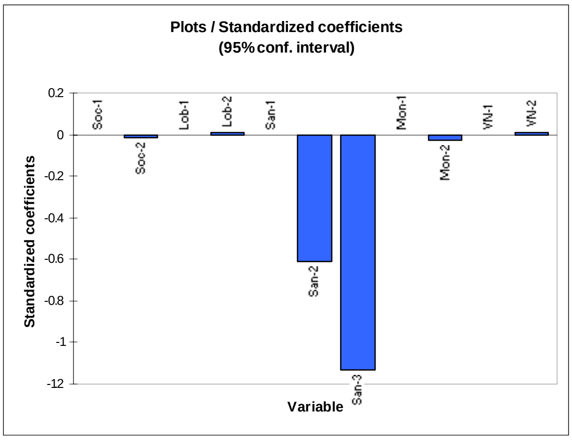
5.4.3.4 New Plot Created Correlation Test

Sanctions and monitoring are the two factors that significantly correlate with the number of new plots created in the ‘business as usual’ scenario, while sanctions, lobbying, village network functioning and the monitoring level, have a correlation with this indicator in the ‘limiting pipe size’ scenario (Table 5.22 and Figure 5.20). Most of these factors have a reverse correlation with the number of new plots created, except for lobbying. Sanctions, village network functioning and monitoring levels contribute to an increase in forest disturbance.

Table 5.22: Correlation test of new plots created

Scenarios	Soc1	Soc2	Lob1	Lob2	San1	San2	San3	Mon1	Mon2	VN1	VN2
Business as usual	0.000	-0.012	0.000	0.011	0.000	-0.612	-1.135	0.000	-0.030	0.000	0.007
Limiting pipe size	0.000	0.008	0.000	0.053	0.000	-0.876	-1.079	0.000	-0.017	0.000	-0.022

'Business as usual'



'Limiting pipe size'

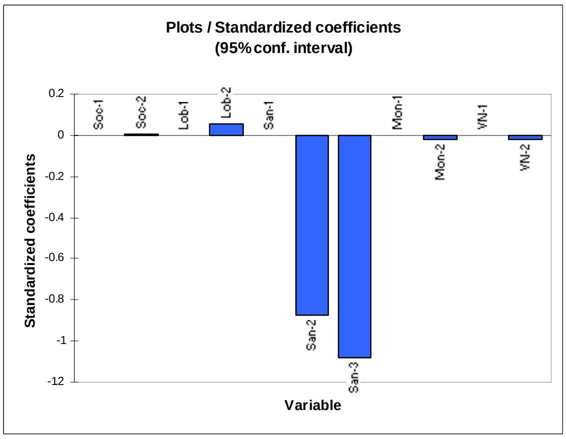


Figure 5.20: Standardized coefficients of new plots created between the two scenarios

The tests of between-subject effects resulting from both the main factor and combination of factors, are detailed in Appendix 1.1.7 ('business as usual') and Appendix 1.2.7 ('limiting pipe size'). The five factor combination that gives the maximum and minimum number of new plots created in the 'business as usual' scenario are: Soc2*Lob2*San1*Mon2*VN2 (64.60) and Soc2*Lob2*San3*Mon2*VN2 (8.50) respectively (Appendix 1.1.8), and for the 'limiting pipe size': Soc1*Lob2*San1*Mon2*VN2 (294.90) and Soc2*Lob1*San3*Mon2*VN2 (7.70) respectively (Appendix 1.2.8).

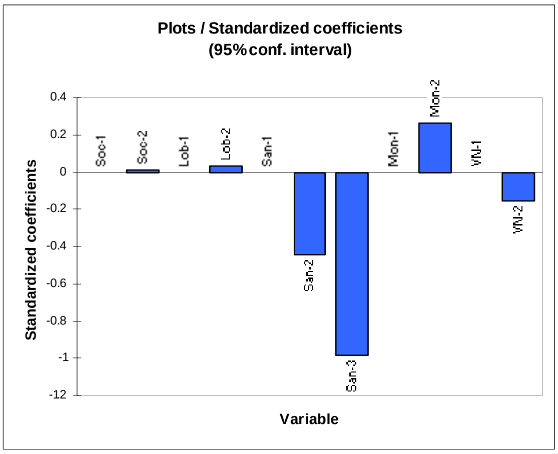
5.4.3.5 New Plot Found

New plot found is the number of new plot cases observed and reported to the village network meeting. The sanctions, monitoring and village network function correlate significantly with this indicator in the 'business as usual' scenario, whereas all five factors have a significant correlation under the 'limiting pipe size' scenario (Table 5.23 and Figure 5.21).

Table 5.23: Correlation test of the new plots found

Scenarios	Soc1	Soc2	Lob1	Lob2	San1	San2	San3	Mon1	Mon2	VN1	VN2
Business as usual	0.000	0.008	0.000	0.034	0.000	-0.444	-0.981	0.000	0.260	0.000	-0.154
Limiting pipe size	0.000	-0.041	0.000	0.196	0.000	-0.661	-0.972	0.000	0.056	0.000	-0.328

‘Business as usual’ ‘Limiting pipe size’



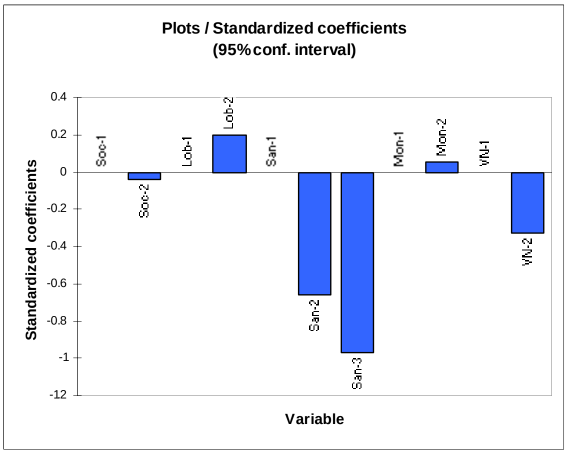


Figure 5.21: Standardized coefficients of the new plots found, between the two scenarios

The five factor combination that gives the maximum and minimum number of new plots found in the ‘business as usual’ are: Soc1*Lob2*San1*Mon2*VN1 (451.80) and Soc1*Lob1*San3*Mon1*VN1 (51.70) respectively (Appendix 1.1.10), and for the ‘limiting pipe size’: Soc1*Lob2*San1*Mon1*VN1 (624.70) and Soc2*Lob1*San3*Mon2*VN2 (8.50) respectively (Appendix 1.2.10).

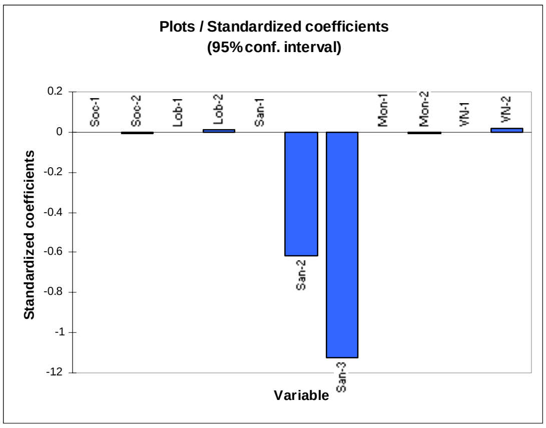
5.4.3.6 New Plots Reclaimed

The sanction is the only factor that significantly correlates with the number of new plots reclaimed in the ‘business as usual’ scenario, while sanctions, lobbying, the village network function and the monitoring level all have a correlation with this indicator in the ‘limiting pipe size’ scenario (Table 5.24 and Figure 5.22). Most of these factors have a reverse correlation with the number of new plots created, except the lobbying.

Table 5.24: The correlation test of the new plots reclaimed

Scenarios	Soc1	Soc2	Lob1	Lob2	San1	San2	San3	Mon1	Mon2	VN1	VN2
Business as usual	0.000	-0.006	0.000	0.009	0.000	-0.618	-1.126	0.000	-0.009	0.000	0.015
Limiting pipe size	0.000	0.009	0.000	0.051	0.000	-0.878	-1.077	0.000	-0.013	0.000	-0.018

‘Business as Usual’ ‘Limiting pipe size’



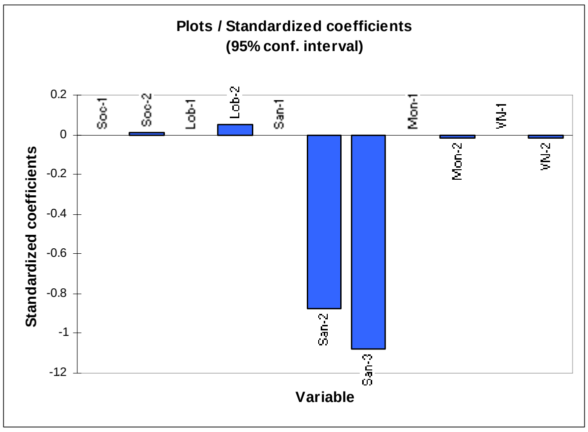


Figure 5.22: Standardized coefficients of the new plots reclaimed between the two scenarios

The results of the between-subject effects test on the main factors and combination of factors are shown in Appendix 1.1.11 (‘business as usual’) and 1.2.11 (‘limiting pipe size’). The five factor combinations that give the maximum and minimum number of new plots created in the ‘business as usual’ scenarios are: Soc1*Lob2*San1*Mon2*VN2 (59.40) and Soc2*Lob1*San3*Mon1*VN1 (9.50) respectively (Appendix 1.1.12); and for the ‘limiting pipe size’ scenario: Soc2*Lob2*San1*Mon1*VN2 (297.10) and Soc2*Lob1*San3*Mon2*VN2 (7.30) respectively (Appendix 1.2.12).

5.4.3.7 ‘Limiting pipe size’ Score and Correlation Test

The pipe size at the initial step is equal to 5 each time; if the rule is created the pipe size will be reduced by 1, the possible minimum pipe size is 2. Thus, there will be a maximum of 3 times that the rule can be used. To analyze the effectiveness of each scenario toward emergence of the water rule, the number of time steps used to allow the rule to emerge is applied. The efficiency score of each simulation can be calculated using the following method:

$$\text{Score} = \sum_{n=1}^{3}(T\max - Tn)$$

$T_{max} = 96$

$t_{n} =$ number of time steps at the emergence of the water rule *n*.

The correlation test results in Table 5.25 and Figure 5.23 show that at the 0.05 significance level, the sanction, lobbying and village network function significantly correlate with this score. All of these factors support emergence of the water rule.

Table 5.25: The correlation test on the effectiveness of the water rule

Scenarios	Soc1	Soc2	Lob1	Lob2	San1	San2	San3	Mon1	Mon2	VN1	VN2
Limiting pipe size	0.000	-0.038	0.000	0.116	0.000	0.329	0.282	0.000	-0.024	0.000	0.115

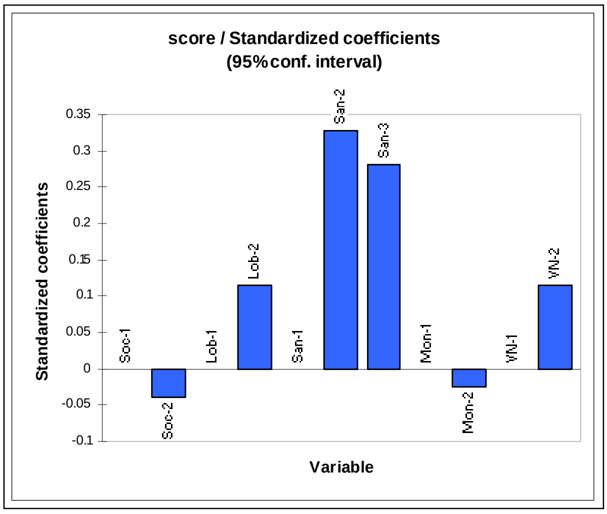


Figure 5.23: Standardized coefficients of the effectiveness of the water rule

The effects of the combination of the five factors that give maximum and minimum scores are: Soc1*Lob1*San3*Mon1*VN1 (212.10) and Soc2*Lob1*San1*Mon1*VN1 (113.90) respectively (Appendix 1.2.14).

5.4.4 Results Discussion

Table 5.26: Summary of the correlation of the five factors with the observed indicators

	Business as Usual					Limiting pipe size				
	Soc	Lob	San	Mon	VN	Soc	Lob	San	Mon	VN
Cash			+				+	+		+
Income distribution inequality			-				-	-		-
Failed plot			-					-		-
New plot created			-				+	-		-
New plot found			-	+	-		+	-		-
New plot reclaimed			-				+	-		-
Water rule emergence							+	+		+

For the 'business as usual' scenario simulation, the sanction period is the main factor that determines all the indicators, except the new plot found of which the monitoring and village network function are co-determinants (strict rules imposed). For the 'limiting pipe size' scenario, the lobbying, sanction period and the functioning of the village network are the main factors that affect all the indicators.

Imposing a sanction period helps increase the total cash income of the whole system; however the increased income is not equally distributed to all the farmers. In both two scenarios the sanction period promotes crop productivity by reducing the number of crop failure plots and the forest area disturbance (new plots created, new plots found and new plots reclaimed). It can be explained that the sanction rule affects those farmers whose farmland is located in downstream areas and who decide to create new farm plots to increase crop production, after experiencing a crop failure. If such a farmer is sanctioned he or she can no longer create new farm plots, thus his or her cash income declines whereas this measurement allows more water to be applied to the upstream farmlands.

Under the 'limiting pipe size' scenario simulation, the effects of lobbying and the village network function on total cash income and income distribution inequality are similar to the sanction period. If the village network functions strongly, there is a high tendency for new farm plots to be withdrawn, thus the total cash income increases but this benefit is not equally distributed among the farmers. The lobbying system tends to support or help the owner of the new farm plot, thus weakening the village network function in claiming new farm plots. Therefore, this leaves new farm plots in upstream areas, leading to water shortage and crop failure problems. However, the greater the number of new farm plots, the more new plots are discovered and withdrawn.

The lobbying, sanction period and the village network function support emergence of the water rule. It was discussed earlier that the water rule, by limiting the irrigation pipe size and water use, gradually suppresses the water shortage problem, and increases total cash income and distribution. Although it shows promising signs; however, this cannot achieve its goal within the 96-simulation time step.

5.5 Discussion

The 'business as usual' scenario and the 'limiting pipe size' scenarios are different because in the former case the village network has only a monitoring and sanctioning function, while in the latter case the village network is in charge of both water and forest management, with the potential to craft or adapt a rule. As water management has an effect on forest encroachment, the situation is more complex in the latter case. The results show that in the former case the sanction is the main factor, while in the latter case, which is more complex, lobbying and the strength of the village network are also important. The general lesson is here that the internal dynamics of the network affects the watershed dynamics and consequently, this aspect should be tackled when studying watershed management. This will be discussed in the next chapter.

CHAPTER 6: DISCUSSION

The research question formulated in the introduction was: From the existing approaches, within the context of multi-level of stakeholder organizations (individual and institutional) and the multiple layers of policies and organizations involved, the research questions can be formulated as follows:

- How can the companion modeling approach and mediated tools be employed to promote the mutual and adaptive learning of stakeholders with regard to understanding the roles and consequences that may arise from individual actions, and the interaction between them? and
- How can the participatory approach and its mediated tools be applied to promote collective watershed resource management?

This study has already proposed an approach for adaptive learning and collective water resource management. This chapter discusses three different topics. The first section is a discussion on watershed management related to the simulation results, which focuses on the role of the local policy network as a core institution for adaptive learning and watershed management. The second section is an assessment of the field results, to evaluate how much was actually learned and what is the contribution of this work to Maehae watershed management. Finally, the third section is a discussion on the contribution of this work to the field of participatory simulation and companion modeling.

6.1 Contribution to Integrated Watershed Management

The model developed through repeated interactions with stakeholders and the scenarios simulation, lead to two discussions. The first discussion will focus on the importance of those specific actions which have an influence on watershed management, in particular: monitoring, rules and sanctioning. The second discussion will focus on the importance of networks for watershed management.

6.1.1 Institution and Adaptive Management: Beyond the sanctions.

Several authors have worked on watershed management and a specific group has emphasized the role of institutions. Ostrom (1994) defines institutions as the set of working rules governing the behavior within water allocation and distribution patterns, and resource mobilization. All over the world scholars have looked at the implementation of these rules and very often have carried out studies at the level of water user groups (often called water users associations). This is an intermediary level between the individual farm and state regulations. A water user association is a local organization that lies outside the government bureaucratic organization, and is formed at the community level. The design of institutional arrangements within such organizations is an initial issue. However, the mere existence of rules does not guarantee the emergence of an optimal pattern of behavior. Since a water user association uses more than one set of rules for different activities and occasions, a thorough analysis is needed to understand the dynamics of institutional arrangements, and examine the ways in which these arrangements constrain or enhance the performance of irrigation systems.

Joshi et al. (2000) analyzed 231 farmer and agency managed irrigation systems in Nepal. The important result of this is that farmer managed irrigation systems with stronger institutional bases, such as the effective imposition of fines, social sanctions and the employment of local monitors, creates a conducive environment for the following of rules and the development of mutual trust among users, and thus yields higher irrigation performance. They found that the institutional factor that contributes the most is the imposition of fines on rule breakers. The presence of a greater proportion of irrigation systems categorized as being in excellent condition, are the situation in which sanctions are likely to be imposed. Written rules and the existence of an official guard fail to show a significant association. The mere existence of monitors does not guarantee that irrigation will perform better.

The results obtained through the simulations lead to similar conclusions for the management of an irrigated system. The study focused on the village network, which is the type of intermediary organization that exists between the individual and governmental agencies, and explored its role. Like Joshi et al. it was found that sanctioning is the most important factor to influence the key dimensions: the resources, the overall economic performance and the level of equity. However, a more diverse set of influencing factors was found when the organization is in charge of rule creation and rule adaptation. While the ‘business as usual’ scenario is only oriented towards retaliation (more or less effective), the ‘limiting pipe size scenario’ corresponds more to an adaptive management scenario. Moreover, in this case, unlike the work of Joshi et al., the village network deals with the whole watershed management process. Thus two resources, water and forest have been considered, as well as the decisions taken on one resource have an effect on the other.

In the ‘business as usual’ case, the village network is informed of the encroachment problems and eventually sanctions the offenders. The higher the sanction level, the better the performance. In the ‘limiting pipe size’ scenario, the village network receives information about the villager’s problems, crafts a new rule and adapts the rule accordingly. Unsurprisingly, the performances are better. This is not surprising, but corresponds to the actual research themes of researchers working in the field of common resources: “*successful commons governance requires that rules evolve…Be prepared for change. Institutions must be designed to allow for adaptation because some current understanding is likely to be wrong, the required scale of organization can shift, and biophysical and social systems change. Fixed rules are likely to fail because they place too much confidence in the current state of knowledge, whereas systems that guard against the low probability, high consequence possibilities and allow for change may be suboptimal in the short run but prove wiser in the long run. This is a principal lesson of adaptive management research*” (Dietz et al., 2003). The information brought-out by the

Maehae model and the simulations is the fact that in this case the sanction level is not the only factor which influences the decision. Lobbying and the strength of the village network also become influential factors. This means that the adaptive capacity of the village network depends on the interactions which occur within the social network.

The results open the door to the study of the functioning of networks which are in charge of the various dynamics at stake in a watershed: there is a need to open the 'black box' and understand the internal dynamics of these organizations. The study has shown that agent-based modeling can be a useful tool for that purpose.

6.1.2 The Role of Networks

"Perhaps the most important remaining task for understanding the role of policy networks in providing a regional integration of governance is the systematic exploration of the impact of networks on the policy outputs and outcomes of agencies involved in local networks." (Schneider et al., 2003).

Several scholars have pointed to the role of networks in adaptive management. They stress different aspects, which is identified here and then discussed the contribution of this work, but first of all, a brief definition of networks in agriculture will be presented.

Lubell and Fulton (2008) define policy networks as interconnected actors in a policy subsystem who communicate information about policy through some social connection. For them the concept of policy networks has evolved through three traditions of research:

- The classical diffusion of innovation model and its offspring, Classical diffusion of innovation models emphasize the importance of policy networks as part of "the process by which an innovation is communicated through certain channels over time among the members of a social system". Based partly on information derived from policy networks, each member of a social system evaluates the costs and benefits of a particular innovation and then adopts that innovation if benefits outweigh costs. In the context of agricultural watershed management, policy networks include agricultural producers, government agencies, and other local organizations as members of the social system. These networks spread information about the existence and effectiveness of different types of management, the existence of water issues and policies, and the decisions and viewpoints of other producers. Interestingly, some of the earliest and best research applying classical diffusion models to management found networks to be relatively unimportant.
- Theories of social capital. Policy networks also represent an investment in social capital. Social capital consists of networks of civic engagement, norms of reciprocity and trust.

- Theories of cultural evolution. Theories of cultural evolution posit social learning from others as the key mechanism of cultural change. Theories of cultural evolution focus on the role of social learning and policy networks in gaining acceptance for environmental concerns within agriculture. Many producers will look to local agricultural leaders for cues as to which management is most effective and whether or not to support a particular policy program. It is important for local agencies to develop networks with these opinion leaders in order to achieve broad acceptance of new policies.

In this case, the village network is not a classical network through which innovations will diffuse. It is a policy network which is in charge of part of the watershed governance. Connections among the members of the network are fixed and well defined. The connections between network members and the stakeholders are not fixed. These are informal connections which can build on the social capital which have been represented in the model through the 'social network' parameter. It is a Boolean value: in one case farmers who observe cheaters will report them to the village leader and members of the village network, in the other case they may not report if the person in breach is a relative. In this case it has been seen that this parameter has no influence on the results. This is certainly due to the fact that even though farmers will not report on their relatives' unauthorized actions, other farmers may do it. Following the cultural evolution theories, the village network is also used by local agencies to achieve acceptance of policies - foresters consider the village network as a means to control forest encroachment.

6.1.2.1 Different Types of Networks and Co-management

Networks will allow a bridge to develop between the individual level and the higher levels such as national or transnational organizations. For Tompkins and Adger (2008), the expansion of networks of engagement appears to be critical to the enhancement of resilience in those communities affected, or likely to be affected by climate change. Social resilience in this context appears to be promoted through at least two distinct forms of cross-scale interaction:

- networks and community relations of individuals and groups operating to cope with variability and change in everyday decision-making, and
- wider networks of individuals or groups who may be able to influence the decisions that are being made on a local scale.

Adaptive co-management may promote the expansion of networks and thus enhance social resilience. However, it is their networks that enable individuals to engage in the wider decision environment, and that will affect their longer-term resilience. Networks allow individuals to engage in wider decisions. The existence and the usefulness of these networks are determined by institutional as well as social factors. At the community level, reducing the barriers to communication through sharing information and feedback that provides positive reinforcement, are important elements in consolidating networks of dependence. At the institutional level, integrated institutional structures may be better able to support the inclusion of other stakeholders in decision-making processes, and ensure that their needs can be addressed by as wide an audience as possible. Providing space for deliberation within co-management decision-making processes can facilitate this, as can opening up channels of communication and ensuring that important stakeholders are engaged. For Monteiro (2004), the way civil society organizations, municipalities and state representatives articulate themselves within the committee, from a social network point of view, also impacts the watershed's environmental governance. For Schneider, political contracting theories of collective action argue that the benefits of networks flow from their ability to allow individuals to make mutually beneficial exchanges and agreements that otherwise would not take place. Networks enhance the likelihood and scope of policy agreements by increasing available information about potential agreements and enhancing the credibility of commitments to fulfil the agreements. By spanning organizational boundaries in fragmented policy arenas, networks provide information about the myriad details of organizational decision making as well as potential implementation problems in each organization, which allows stakeholders to develop previously unexplored opportunities for collaboration. Networks increase the credibility of commitments by transforming short-term interactions into repeated games in which a reputation for reciprocity and trustworthiness can potentially mitigate the problem of opportunism involved in single exchanges.

In this case, the village network plays an important role concerning relations with governmental agencies. The village network is linked to the Forestry Department and plays an important role in the mitigation of possible tensions with the forest stakeholders. As for the forest, the village network plays this role of co-management. The organizations in charge of land and water management are not actively linked to the village network, though this might be a possibility in the future. The village network is only in charge of local issues. Along the lines developed by the authors above, it would be interesting to connect the village network to larger networks. However, this raises the issue of how much power the administration is ready to transfer to the network. Establishing linkages between several networks leads to empowerment.

6.1.2.2 Some Networks Linkages are Good for Resource Management; Some are not.

For Newmann and Dale (2005), although community social networks can build resilience, and thus aid adaptation to unexpected environmental change, not all social networks are created equal. Networks composed of a diversity of 'bridging' links to a diverse web of resources and 'bonding' links that build trust, strengthen a community's ability to adapt to change, but networks composed only of bonding links can impose constraining social norms and foster group homophyly, reducing resilience. Bodin et al. (2006) consider bonding ties as relations between family members, friends and neighbors in closed, tightly connected networks. Bridging ties give access to resources and opportunities that exist in one network, to a member of another network.

Bonding ties create dense network structures and strong, but localized trust, but can impose strict social norms that discourage experimentation and encourage increased homophyly, which is the tendency of a group to become less diverse over time, and to distrust others. Bonding ties, although needed to provide trust, can reduce a group's diversity and thus decrease resilience by limiting accepted options for the group. Only when social or network capital encourages diversity and experimentation will increased resilience be realized. As previously identified, the authors consider that bridging ties can also act as vertical links, facilitating a network's ability to access more vertical power relationships.

In this case, the village network does not comprehend only bonding ties. The members are from different ethnic groups; they have different origins. This is more a bridging ties network, and through the explanation of the authors above, it implies that that this network has the potential to enhance the resilience of the watershed. Decisions are often difficult, but they are the result of an interaction among heterogeneous actors. The village network creates and maintains these bridging ties.

6.1.2.3 Social Networks as a Capital Problem

Scholars like Lubell (2002) or Schneider (2003) examine the emergence and existence of networks through the economic evaluation lens. For them, as with all voluntary exchanges, partnership contracts are most likely to emerge when potential benefits are high and the transaction costs of developing, negotiating, monitoring and enforcing the political contracts are low. In short, from the contractual perspective, watershed partnerships emerge because they produce mutually beneficial solutions to resource conflicts in the watershed that are superior to command-and-control institutions. The greater the transaction costs of developing and maintaining partnerships, the less likely partnerships will emerge. From the policy perspective, the factors affecting the growth of watershed partnerships suggest advantages and disadvantages inherent in cooperative institutions. Partnerships are more likely to emerge in watersheds facing dispersed management problems that are difficult to solve with command-and-control policies. Partnerships are complements and not substitutes for existing command-and-control policies, which may incur lower transaction costs for higher water quality. Monteiro (2004) looks at another kind of capital: social capital. For him, the amount of social capital within a watershed committee has a direct impact on the overall institutional performance of these committees, and therefore on watershed environmental governance.

It can be seen that the Maehae watershed context corresponds to high diverse area, with different sub-watersheds, various ethnic groups, many governmental agencies and non-governmental organizations. Thus, command and control policies are very difficult to implement, as it would be very costly to monitor everything, follow-up and impose sanctions. The social costs would also be very high. Following Monteiro's ideas, the social capital within a village network is not very high at the start because it includes people from different ethnic groups, upstream and downstream players etc.

Consequently, as the model shows, decisions are difficult to reach. However the village network can be considered as a tool which raises the social capital. People repeatedly meet, take decisions and negotiate. In terms of costs, Maehae village network is certainly worthwhile having.

6.1.2.4 Social Networks: For the Benefit of the Agencies or for the Benefit of the Farmers?

For Scholz (2006), local policy networks can aid federal agencies, but they can also co-opt agencies resources for unintended purposes. The cooptation hypothesis argues that partnerships will magnify the effectiveness of local political cultures in influencing agencies and the firms they regulate, further reducing compliance and enforcement actions in conservative areas, but further increasing compliance and enforcement actions in liberal ones. If this is true, partnerships might provide no net gain or loss to governmental regulatory goals, but may exacerbate existing politically induced variations in enforcement.

In contrast, the transformation hypothesis argues that the development of local policy networks and local institutions transforms the strategic choices of local interests and government agencies by increasing the likelihood of mutually advantageous outcomes, which in turn enhances their strategic preferences for stringent enforcement and compliance. Well-organized local users possess considerable advantages over centralized enforcement agencies in their ability to detect violations, and their stronger motivation to impose meaningful punishments. An effective network not only increases the probability that violations will be detected and punished, but also ensures that allegations and detected violations will be widely publicized among stakeholders of interest. In summary, contrary to the cooptation hypothesis, the transformation hypothesis implies that effective local water policy networks will increase both governmental enforcement and compliance rates, even in conservative communities that would otherwise be expected to favour reduced rates. By providing a focal point around which concerned agencies and groups can organize, partnerships both align interests in support of the governmental program goals and create effective pressures on the enforcement agency and firm alike. The more organized the network, the greater the expected impact on compliance and enforcement.

If one has in mind an authoritative top-down approach, then following the cooptation hypothesis, one can consider that the village network plays in favor of the local political culture; it mitigates the administrative regulations, taking into account local constraints. However, in this case the village network plays a transformative role. It is composed of bridging ties which bring together different cultures (the different ethnic groups, the forester), increasing the probability that violations will be detected and punished. It provides the focal point around which governmental regulations are confronted with local realities and then applied, and around which local initiatives and innovative management ideas can emerge and be tested against with governmental interests.

To conclude, as the literature shows, local policy networks such as the Maehae village network are very important organizations. Their efficiency depends on many factors such as the type of ties, the social capital, the economic costs, the range of issues they can tackle and their connectedness to other networks. Through this research, it has shown that the village network can be modelled with agent-based modelling, thus allowing the exploration of several social and political dimensions linked to management methods, such as monitoring, negotiation and sanctioning. Therefore, this opens the door for new research to take place on policy networks modelling, through new case studies and through more theoretical models.

6.2 Impacts and Outcomes

This section[2] reports on an external evaluation carried out on the Maehae Commod process. The evaluation was conducted by Olivier Barreteau, member of the Companion Modelling network, partner of the project which funded the work evaluated and its evaluation, and a researcher in the field of water management at Cemagref, the French Research Institute on Environmental and Agricultural Engineering, where he uses the same kinds of approaches. The evaluation was actively supported by the authors, as well as Manitchara Thongnoi, a research assistant at the same center who previously performed an evaluation on another case study for the same research project in north-east Thailand. I supported the translation of nine interviews, as well as in organizing the field work (contacting the interviewees, setting up the appointments and driving to the interview locations). Manitchara Thongnoi supported in the translation of sixteen other interviews.

The objective of this evaluation was to understand what has occurred since the companion modelling approach occurred, how it has been perceived by the stakeholders involved in it and how we can explain the dynamics of the process, that is, what in earlier stages could have led to specific activities and results in later stages.

6.2.1 Assessment Methodology

The evaluator considered the interviews as raw sources of information, which allowed him afterwards to answer the following questions:

- What were the specifications of the main issues in the area?
- What led the interviewee to participate, what does he or she remember? - as much detail as possible and organized chronologically
- What changed in terms of the ideas the interviewee has on the socio-ecosystem?
- What has been changed in the ecosystem, as well as in the social system itself?
- Looking back, what are the perceptions of the opening of the process?

[2] This section is based on the evaluation report: O. Barreteau Report on the evaluation of Maehae case study, 2009"

As much as possible, the evaluator tried to push the interviewees to "tell the story" as they remembered, with a technique adapted from biographical methods. The interviews were based on open questions, rather than a story of what happened during the unfolding of the ComMod process according to the interviewee.

The interviews were mainly held with villagers. In all, 22 villagers, the forester and two field assistants were interviewed over a five day period spent in the area, either at the interviewees' homes or in their field. Two facilitators from the game session were also interviewed. Among the villagers, twelve were former players in the gaming sessions. The evaluator selected a sample of these players with the constraint of matching the ethnic group of players (Hmong or Karen), the various roles in the game (the farmers' types), the game type (forest game and water game) and the session. When possible, players who participated in several games were interviewed. However we also obviously had to deal with the constraint of changes that had taken place in the population since the game sessions: several former players had moved out the area, mainly after getting married. The ten other villagers were chosen due to their role in the second stage of the process. I selected the people most involved in the process of conflict resolution. This selection was composed of community leaders, influential village headmen, the head of the Village Network (VN), a representative of the area at the local administration level, but also more regular members of the village network, as well as those who ensured the interface between lay villagers and community leaders took place. We also decided to interview the forester, due to his key role as far as natural resources management is concerned, but also because he participated in one session of the forest game. Moreover, the forester also acts officially as a consultant for the VN on specific activities, such as forest fire prevention, and he participates regularly in the monthly meeting of the VN, where he is not very active. Also, the RFD provides money to pay *per diem* to VN members for participation in the meetings. We interviewed field assistants and game facilitators to have complementary view on the process, its implementation and its dynamics.

The long period of time since the beginning of the case study has been a concern, which the evaluation team expected from the beginning, and proved to be problematic, since several interviewees did not remember very well or at all, their involvement. However, following the example of Bull et al. (2008), who evaluated a public engagement process ten years after the event and showed that even when interviewees have forgotten all the processes, they can provide information on the knowledge they elaborated and retained from the process. To take this into account, the answers from the interviewees were first interpreted according to their memory of the case studies themselves, but also according to the evolution in their practices, their knowledge and their view of the environment since the time the researcher started to work in the field.

Besides this first source for analysis, we used a framework under construction, and meant to describe collaborative governance processes for adaptation to climate change in natural resources management (Emerson et al. 2009). The evaluator participated in the construction of this framework.

6.2.2 Influence of the Context on the Companion Modeling Process

The context of implementation is central to understand the dynamics generated by the ComMod process. The evaluator has also to push the analysis in this direction because a clear dynamic of change is at stake in this case study, and following studies in the domain of organisational change, it is required to take into account the triple contingency of time, people and tools, in order to understand changes in an organisation (Miettinen and Virkkunen, 2005).

Besides all these development projects, Maehae is a place with a lot of ongoing research. The attempts to get rid of opium, to develop new intensive cropping patterns while preserving local resources, have focused a lot of attention and means here. As an entrepreneurial village headman told us, “if researchers from this project leave, we can have other supporters”. On his house, a board lists all the coming appointments and meetings he has. The board is full, and includes several discussions with researchers.

All these projects and research, as well as development activities, are identified by the local population with government agencies, and thus are seen as sharing the same objectives: protect the forest and ensure the economic development of the area. Most of them also call for the involvement of villagers. This case study somewhat covers all these simultaneous activities and it is difficult for villagers to identify between all these research projects and more broadly all these development projects, even more so since the objectives of this study fall in the same broad category of natural resources conservation as those of others. In addition, these other projects provide networks for villagers, as well as the possibility for comparison with other places facing the same issues.

Despite the context of multiple research and development projects, thirteen out of the 22 farmers interviewed could see the difference between the process led by the researcher and other recent processes, even five years on. Only three interviewees could not identify at all the process led by the researcher, even after the researcher[3] showed pictures from the collective events within which they were participants. All these villagers who did not identify the process had been participants in the first stage. Evidence for this identification came very clearly in some interviews: “I was used to meetings but this one was different” (N1)[4], or “others came but were not successful” (N16). The identification can be also directly measured through their way of retelling the unfolding of the game session they participated in, or the sequence of collective events during the second stage. Several interviewees were rather precise and accurate.

---

[3] Below “the researcher” is me.

[4] Quotations are not exact, they have been transformed though the translation and understanding of the researcher. We keep this format of quotation to distinguish these items as direct empirical material.

This identification is not necessary a complete separation. Interviewees were able to identify relations between the various research or development projects, and further to identifying this research among the whole set of research and development projects, some interviewees were able to remember the case study as a part of a whole set of activities coming from outside. They considered these projects as complementary and all useful in their diversity. They needed these multiple dynamics to help sort out the water issue.

The identification of the process in finer detail, by participants who had a repeated involvement, is more blurred. A few interviewees, such as (N7), participated in two game sessions and could not separate them in their memory. The identification of learning from the process was more blurred among some participants in the first stage. Some players directly attributed the benefits of learning to the process, for example, the orientation of cropping lines or the setting of terraces to the game, while it was not an issue at all.

If the existence of many other projects has not made difficult the identification of a process based on a lot of single events, it has raised some comparisons on the condition of the involvement of villagers among a whole set of research, as well as development projects. Several interviewees mentioned that the researcher brought less money than other projects. Experience with other projects had raised their expectations on direct feedback, such as money, food, signboards etc. Hence if the case was of low interest, it made it more difficult for the project to be accepted by some villagers.

The presence in the area of a researcher, working on the same issue as that of a major conflict in the area, willing to join in with the activities of the Village Network and well accepted by the villagers, was also an opportunity for the Village Network. Moreover the researcher had a special status: he was an outsider, well known among the government agencies, without any specific agenda in the area besides completing his Ph.D., which was not perceived as potentially harmful to the community. This status was therefore an asset. Last but not least, he was nearly cost free for the villagers. All this entailed strong involvement in the conflict resolution stage. The researcher was also neutral in terms of the Hmong/Karen relationship; therefore, he was welcomed, because all parties were very cautious about accepting any ideas coming from the other side.

A few other contextual elements generated side effects during the implementation of the process. The status of researcher, an *Ajarn* (teacher), also facilitated participation in the gaming stage. Besides the welcome mediator as explained above, the researcher benefited from positive prejudices, as he was expected to provide interesting new knowledge, and so some players came forward because the project was organized by an *Ajarn*.

This status also came into play in relation to the land tenure issue. This time it was rather the confusion of the status of the researcher with other research and development projects which was the issue. One interviewee mentioned that one reason he came to a game session is that he hoped it could help him one day get ownership title. The researcher thinks this was rather due to the confusion over two processes happening at the same time: his companion modelling process and a survey for land reform helped by the Land Development Department and the Land Reform Department. These two agencies were aiming to determine who owned which plot of land. Moreover the researcher was afterwards able to gain information from them (such as GIS maps) and use these with the villagers in workshops during the second stage.

6.2.3 Influence of the Context on the Results

As mentioned in the description of the context, although a lot of outsiders including government agencies are present in the village, there is a lack of authority to enforce any agreements set up by the community and put them into practice. The regular presence of relevant Government officers is missing, but the suitability of existing laws in relation to the complexity of community needs and their informal rights is also a concern. One of the officers present in the area told us that he needs laws to help him implement the natural resources management policy. While many laws actually exist: he mentioned a lack of suitable laws.

Furthermore, the division within the community makes it difficult for the village network to play this role. The continuous tension between the identification with the place and identification within the ethnic groups makes implementation difficult, meaning that transformation of the outcomes from the process for collective action is limited. Practically, the village network is the place for setting up agreements, but it has no power for the enforcement of these agreements, and so has to convince villager leaders to push for their implementation. These leaders use their moral authority to convince the villagers to respect the agreements; however, this moral authority is built upon ethnic group cohesion. Thus they have to find the right path, sometimes at the expense of their own leadership group. Then, when a case occurs of conflict between villagers regarding natural resource management, it comes back to the village network to resolve it. It has therefore been very difficult to transform knowledge into action at the community level. Several interviewees, from lay villagers to community leaders, called for support for a more stringent external enforcement of the law.

6.2.4 Effects and Efficiency of the Companion Modeling Process

In this section, the context of implementation of the ComMod process, as well as the context of the evaluation, as described earlier, makes a strong caveat for any discussion of the effects which could be directly related to the ComMod process: too many parallel processes intervening in the area and the long lapse of time make it difficult to disentangle causes and effects. Furthermore, it is difficult for the interviewees to take the beginning of the case study as a starting point; therefore, changes reported do not necessarily fit with the timing of the researcher’s intervention.

6.2.4.1 Direct Effects.

Interviews show a balance in direct effects among participants: six did not mention any direct effect, eight mentioned effects at a cognitive level only, eight mentioned effects at both the cognitive and action levels. Direct effects at the action level include some trends; some interviewees considered that stopping the problem of encroachment in the conflict area, even if the case has not been fully settled, is already an effect.

Cognitive effects include knowledge about the dynamics of the system, and the understanding of potential consequences of actions within these dynamics. Interviewees think they understand better the water dynamics, but also the consequences of market fluctuations. Two interviewees clearly reported that they started some reflexive approaches within their own farming practices as a result of their participation in the game. Several interviewees also mentioned that they acquired knowledge of others' knowledge.

At a more collective level, effects deal mostly with attitudes, for example, to discuss natural resources management issues as more the concern of others or more the concern of the resource. Community leaders involved in the second stage mentioned more specifically learning at their level of leading a collective process in a more collaborative way. They learned from the facilitation of the researcher how to involve participants actively and provide feedback to them. They also reported that they learned about relations with government agencies. Cognitive effects also deal with the overview of the area, and knowledge about the location of cultivated and forest area, as sustained by several artefacts. The support of the maps allowed participants to focus on the boundary areas.

However, a few cognitive direct effects have risen to the transformation level; into action and practice. At an individual level, a few effects have been generated directly from the game, such as planting fruit trees on slopes to prevent erosion. More surprisingly, some topics marginal to the game, such as the use of pesticides, which some interviewees reported to have modified after participating in a game session, were revealed as having taken place. This may be due to confusion between the game session and other activities.

At the collective level, some joint actions, such as setting firebreaks, are reported to have been a direct impact of the game. Some rules for water sharing seem to have emerged as well. However, it is not clear if these came really from the game or if they came from other projects present at the same time. Interestingly, some interviewees mentioned rules for water sharing at the local level (with neighbors) while the water game was aimed at fostering the emergence of rules between upstream and downstream parties. However, the distance between farmers in the real world seems to have been a strong limiting factor on the implementation of this kind of agreement. As one downstream farmer who used to play in the water game told us, “I don't know what they do upstream". It is considered beyond their scope of control, and they do not have to deal with it. Finally, the second stage also induced rules for individual practices, such as setting a minimum distance between the stream and the fields.

6.2.4.2. Capacity Building

The effects of the process on capacity building are rather controversial. Half of the interviewees reported an increase in their awareness of natural resources conservation needs. This is difficult to test as such through the short time of the evaluation, allowing for only one shot at interviews. At the same time, the game has also been considered as being so close to the reality it could not bring any new insights. One interviewee (N16) said that since he is local he knew everything better than the researcher about NRM, before he arrived. To further the discussion on this point, it is necessary to open it up according to the various categories of learning, from an increase in awareness of transformational knowledge according to the object of the new capacity, from organisational to agricultural practices and land tenure issues according to their relation with that kind of collaborative process, and finally according to the target of this capacity building.

Most interviews showed at least in the discourse an increase in awareness about local NRM issues, with no possibility of linking it to the ComMod process. With all the projects on these issues in the area, hopefully villagers have built knowledge at least on an awareness of the issues, but with some interviewees it went further to include transformational knowledge. Some farmers changed their cropping practices to less water intensive processes and some leaders implemented a new way of leading, such as a collaborative decision making process, on other issues.

In the second stage, the capacity building leans indeed more towards attitudes and ways to lead a dialogue process. If people's concerns have truly evolved according to the researcher, a change in attitude towards the resource is more doubtful, except with the community leaders who have been deeply involved. New attitudes and new capacity with a significant indication of transformations into action, are thus more important in the domain of collaborative decision process management than with forest encroachment itself.

Also, in the second stage one leader interviewed mentions a better understanding of the sense of owning the land. In the land tenure context, this is potentially important for future development of the area, as it has changed the view on land issues.

This capacity has led to new know-how in that field. Community leaders have learned the possibility of making a space for all voices. This has gone up to the implementation level in some small cases. This area is close to autonomization in terms of the way of dealing with NR conflicts thanks to the presence of a few key people and the capacity they received from the ComMod process. There are also indications of capacity building on a secondary level, through the attitudes towards the experiment. For example, one player elaborated assumptions on his interest for taking up “integrated farming”, on the basis of the game session. He then tested this diversification on part of his land. There is no clue as to whether this is really linked to the researcher’s intervention; however, this does provide optimism about the capacity of the area to go towards adaptive management. One player who had forgotten the game has also taken up experimentation. The game generated a process of maturation for some farmers; to reflect on their own practices. One interviewee said clearly that what he learned came through playing the game, and not from a kind of “take-home message” delivered by the researcher. This occurred in the first stage only at the individual level, because this stage was designed to capture these individual practices and knowledge; hence, it did not involve people in charge of collective responsibilities, so neither did they lead the simulation toward these collective issues.

On a broader level, the process also increased the capacity of villagers to be at ease with the various tools and artefacts this kind of collaborative process is very used to. For example, in this case, villagers have learned to use maps, provided cautiously by the researcher, and how to refer to them.

Finally, probably the most important capacity building aspect introduced was the training of field assistants over the longer term. These people constitute resources for the future, as the external people community leaders mentioned they need. However these resources cannot be efficiently utilized without the institutional support to hire them and be able to push through the agreements coming out of the community. This capacity has been tested with the creation of a committee at the village level to build and manage a pipe for domestic water use. The field assistant has also developed the capacity to use the games, as she did so to organize a dialogue for sharing money between two villages.

6.2.4.3 Secondary Effects

This subsection deals with two various types of secondary and indirect effects: on the environment and on people. We consider here changes which occurred as a consequence of changes induced by the ComMod process, and we also include changes for which there is no proof that they were related to the ComMod process and no other.

The relatively low rate of transformation of knowledge into action makes these secondary effects rather low in scale. Several leaders have given up since, partly due to their disappointment with the lack of resources required to ensure the enforcement of agreements. The dynamics may be in decline, and this is confirmed by one former field assistant (N9); concern about natural resources conservation was raised during the process but declined after the researcher had left. On the social side, the emergence of new smaller networks, homogeneous on the ethnicity side, is also a bad indicator.

The effects on the environment itself are more difficult to assess. The perceptions of the interviewees are that these have been very low, for the same reason that there is a mix of potential causes and because of the time lag required to see the changes. We could not get hold of a map in order to give an objective comparison but due to the caveats mentioned above, it is not clear if it could bring a lot of information anyway. We have thus used the perception of interviewees to get some information on that point. These perceptions are rather heterogeneous, as explained in the following paragraph, but participants all claim the observation of nature (forest, water and water flow) to sustain their assessment. These assessments are linked to their relations with the natural resources. For example, it is specified that farmers do not lack water anymore; however, the natural variability of resource dynamics due to climate does not allow this conclusion in reality. A major drought occurs every five years on average in the area, though none has occurred since the water game was played. A good test of the robustness of all the changes in the practices and rules implemented will be when the next major drought occurs.

Most interviewees see a reduction in encroachment, and a stabilization or even an increase in forest area, as well in water availability. However, their definition of forest is unclear and it seems that some of them include fruit trees which have been planted on the slopes in this category. The natural variability of water availability does not allow a clear evaluation to take place on this point, also because a moderate amount of work has been carried out on the streams in order to collect more water, such as the building of small dams and the laying of water pipes.

Socially, interviewees have a rather positive view of others and tend to see less encroachment, or they think that globally the community has reached a better level of understanding. There is at the same time a perception of an improvement in others behaviour, as well as an improvement of the perceptions of others. Another side effect at the collective level is related to the increase in the capacity of stakeholders to organize collective processes. It looks like capacity building when dealing with collaborative processes has been, at least for one leader, transformed into action. A former head of the village network has implemented these attitudes to resolve cases using negotiation, in the absence of the researcher. Capacity building related to know-how on collaborative decision making has been efficient in this case.

6.2.5 Further Stages

This case study currently features a high level of uncertainty. Many leaders have been dismissed and have not been replaced. Agreements have not been enforced, and in the meantime a lot of changes in attitudes have occurred and new knowledge introduced. It looks like Maehae is on the edge, at a juncture. The issue is whether the system will be able to build on these new resources, or whether it will go downhill, with increasing division amongst the villagers. A follow up on the activities may help; presentation of the model built on the basis of the knowledge obtained in this ComMod process could be a way to revive collective thinking in the village. Experience with the two first stages should lead the community to pay attention to the involvement of people at various levels, in order not to lose community leaders who might engage in a joint process.

In fact, presentation of the tool made by the researcher could a good opportunity: it does not directly engage participants but can lead to discussions about the real issues.

Several resources are missing and could be provided for from outside the area. The most important are legitimate external referees to help enforce the rules set up collectively. Due to internal divisions, it is important that any constraining rules are enforced by external actors, but these actors have to be legitimate and trusted in the eyes of the community. This may be difficult in the case of Maehae, where the officers of regulatory agencies are not necessary welcome, because they come with external rules that nobody wants in the area.

Together with these legitimate people, the area needs suitable laws to cope with the current flexible practices and to provide incentives to improve the management of natural resources.

Money does not appear to be a key need in the area. Many recently purchased pick-up trucks, and a steady trade in the shops shows that money is present at the individual level, even if it is not evenly distributed across the population of the area. This, at first optimistic view on that point is tempered by a few other interviewees who explained clearly that money is missing and that even if they understood and learned the negative consequences of taking out weeds or leaving the slopes without trees, they would still do the same because of a lack of money. Therefore, the immediate financial return from practices unkind to the environment is too high, even with the penalties in place, and this is a strong incentive for people not to respect rules, which are too focused on conservation.

6.3 Contribution to ComMod and Participatory Modeling5

6.3.1 General Comparison with other Companion Modeling Processes in South-East Asia

The ComMod process is usually comprised of different steps (field investigation and literature study; modeling and scenario simulations). The adaptive organization of these stages and the iterative use of tools within the process depend on the specific context and the changes that may occur along with the process. In this paper, we present a specific ComMod implementation, the aims of which are to understand the process of land, water and forest management in a watershed, enhance collective learning and facilitate dialogue on watershed management. In this discussion, we first examine three ComMod processes conducted in Asian mountainous areas, those which have lead to different interactions with stakeholders and different uses of the model and tools, and then underline the specificities of this approach. The impact of the ComMod

[5] This section is part of an article accepted with major revisions in Environmental Modelling & Software.

approach in terms of establishing linkages is then discussed. We end this discussion with a brief point on the complementarities between participatory modelling workshops and active observation of existing negotiation platforms, such as the village network.

Barnaud et al. (2007) translated an ABM that integrated scientific knowledge on biophysical processes and agricultural practices, initially built by researchers, into an RPG aimed at sharing the scientific perception on agricultural dynamics and its consequences on soil erosion. The stakeholders validated part of it and asked the scientists to modify the RPG and use it for other topics. The first topic they identified was access to credit and the second was water management. The RPG was modified twice to integrate the new knowledge acquired during the game and the participants' suggestions for improvement, and then it was used for participatory simulations to support new discussions and the exploration of the scenarios. It was also used to initiate negotiations at higher political levels. In this case, the initial ABM was not used in the interaction process with the stakeholders. A simpler model was developed for participatory scenario simulations. The simulation model can be considered as an initial synthesis of the available scientific model, which was then used as a basis for the construction of the first role-playing game.

Becu et al. (2003) used a specific method (telling stories) to elicit the individual mental models of the farmers on biophysical characteristics and on irrigation systems. The transcript recorded from semi-structured interviews was analyzed to elicit the different elements mentioned by the stakeholders (such as water, credit, banks, pumps and neighbors). Then, an open story was recounted to each individual, letting him intervene and select among different paper cards on which the elements were written. They could also add missing elements. Once the necessary elements were selected, the individual was requested to establish linkages among them, thus drawing a mental model. The numerous mental models were categorized and served as decision-making structures for the computer agents involved in the ABM. Becu conducted three rounds of participatory simulations aimed at exploring scenarios and stimulating negotiation between upstream and downstream stakeholder representatives. Without using RPG prior to presenting computer simulations, he found stakeholders had difficulty in understanding the computerized model and abstract interface, distinguishing between simulation results and reality, and in formulating scenarios to be explored in the model. Stakeholders were reluctant to join the negotiation for compromised solutions, due to unequal negotiating power.

Gurung et al. (2006) initially developed an RPG from formal and informal preliminary analysis in order to facilitate negotiations between two villages in a conflict over irrigation water. After that, the modeler developed an ABM reproducing the RPG and the scenarios identified during the discussion. The ABM simulation suggested that a communication protocol has more effect on the economic outcome than the network structure or the climatic variations. During the first workshop, the stakeholders came to the conclusion that the water-sharing problem had to be tackled at the watershed level, including all seven villages of the watershed involved in the negotiation. A new RPG was developed and used during a workshop including villagers and various officials from different administrative levels. The output of the workshop was the creation of a watershed committee in charge of resource management. In this case, the objective of the ComMod process was to solve a conflict situation and reach a collective agreement. The RPG was used to bring stakeholders together; however, there was no use made of a computer simulation model, which assembles and synthesizes scientific knowledge. These three examples show that the use of models in a participatory process, or even more precisely in a companion modeling process, differs depending on the social context and the objective of this process.

In this case, the initial objective of the study was first to clarify the ambiguous representation of land and forest resource management and second to explore alternative management scenarios. Like for Barnaud et al. (2007) and Becu et al. (2003), and unlike Gurung et al. (2006), there was no specific demand from the stakeholders for a companion modelling process to intervene in a conflict situation. There was a need for a better understanding of the processes at stake and for a common understanding of each other's point of view. Consequently, we started with the design of a land/forest RPG to share the understanding of individual and collective behavior, which are driving the dynamics of the land-use. The agricultural dynamics and the forest management rules are well known. The objective was more to see how each stakeholder, farmers on one side and the forester on the other side, interact and cope with the official rules. Lessons learnt from the land/forest RPG and player interviews confirmed that Maehae people and the local forester could compromise over farmland and forest access, as stated in Lebel (2005), but this relationship would vary with a specific context such as a period of drought, when the focus would shift to the water management problem. The problem for this second step was different: there are no administrative rules for water management, with a given player in charge of verification and enforcement of the rule, as was the case for the forest. Consequently, the workshop on water management was more exploratory. The RPG was a new model; it did not include any component of the previous land/forest game and the objective was clearly to explore the reaction of stakeholders facing water shortages and identify and discuss collectively the possible scenarios. After these two different participatory modelling exercises, we had enough knowledge to build a model on the watershed dynamics, but we were lacking the collective dimension of the decision-making process. Thus, we participated in the monthly meetings to understand and grasp the functions of the village network. We facilitated and co-organized focus-groups meetings at the village, village network and inter-institutional levels, which helped in formulating management plans and scenarios.

At this stage, we had sufficient knowledge and understanding of the system as well as scenarios to assemble an ABM that synthesizes the knowledge on decisions and interactions on land, water and forest. The process is a process of collective knowledge elicitation. Several simple models were conceptualized and implemented as RPG. The knowledge gathered served to implement a synthetic model, which could be simulated to explore those scenarios that were discussed and formulated by the stakeholders. Unlike Barnaud et al. (2007), who started with a scientific model to assemble scientific knowledge, and unlike Gurung et al. (2006) who did not use any synthetic computer model, but like Becu et al. (2003), we placed the computerized model at the end of the process. Now that the model was complete and could be explored under different scenarios, the next step was to present the results to the stakeholders and explore the scenarios with them. The simulations that we present here do not give material from which we can expect major changes in the system. In brief, the simulator shows that the functioning of the village network leads (with some delay) to the same results as the simple top-down regulations which often prove to be inapplicable. While Gurung et al. (2006) used the companion modelling process to reach an agreement among conflicting stakeholders, and Becu used the companion modelling process to elicit individual knowledge, we are closer to the approach used by Barnaud et al. (2007). At the end of the process, there is no emerging solution for a given problem, but the modeling process was effective in establishing linkages and revealing relationships. When the process started, the identified issue was that of forest encroachment: we have underlined that this issue should not be treated separately from the issue of water. When the process started, the perception was that we had on the one hand the forest component, which was clearly regulated by a top-down procedure, and on the other hand an absence of regulation for water management. We have shown that these two components are linked and the village network is an active organization, which considers as a whole the forest regulations, the water constraints, as well as the social dynamics. The simulations show that the functioning of this village network leads to satisfactory levels in terms of efficiency, while being slower than the top-down regulations. However, we can consider that the village network plays a mediating role, favoring the application of regulations and maintaining a degree of flexibility. The focus is now on enhancing and facilitating the actions of the village network.

6.3.2 Position and Role of the Researcher

This case has two stages. These two stages have different purposes, which both fall within the “ComMod 1” type, according to the charter (collective learning). However, this case study is a good example of evolution along the process from a “ComMod type 1” to a higher integration local decision process, building on the trust generated by the ComMod process. The second stage (village network negotiations) is actually a true mix of “ComMod 1” and “ComMod 2” (collective action). From the researcher’s point of view, the second stage aims at gaining new knowledge on institutional processes in conflict management situations about NR. However, from the community leaders’ point of view, this second stage mainly contributed towards coming up with agreements on encroachment and water management. Such a mix is rather original. The sharing of control of the process has made it possible. The second stage has been collaborative, with both the researcher and community leaders having their own purpose. In the majority of implementations of Companion Modelling, the researcher keeps control, and is the subject who learns or facilitates.

This leads to another specificity of this case, which is the stance of the researcher in the second stage; close to a participant observation stance. While the Companion Modelling process is usually generated for its own purpose, in this case the researcher fitted in an ongoing process which would have occurred anyway. He brought in the methodological knowledge and attitudes specific to the ComMod stance, but did not organize a parallel process. This is particularly interesting in the context of emerging critiques of participatory approaches on stakeholder fatigue, and even more in this case when several parallel processes are already taking place.

This original stance has several side effects. Conducting companion modelling as a participant observation exercise requires a cautious approach and a fine tuning of interventions. The evaluator might observe that the process has been heavily personalized around the intervention of one "Commodian" only, one who has been deeply involved in the project over a long time. Such an individualisation of the ComMod intervention is quite specific to this case.

Other side effect is the low insertion of stakeholders in the ComMod process, which was hidden to them. It has instead been an increasing insertion of the researcher in the collective decision processes. This has made an unusual contrast between a low insertion, but a high acceptation.

Finally, this case represents a weak distance between collective workshops and the daily concerns and stakes of participants. This is not surprising during the second stage, but even during game sessions, the close relationship between game setting and real life, as noticed by the participants, led them to discuss real, current issues instead of devoting more time to exploring future situations or alternative management patterns. Their weak understanding of the game led them also to take it as an opportunity, rather than a collective exercise to explore alternative collective behavioural patterns.

With this case, the most usual benefits of a ComMod approach are also present: a better understanding of others' constraints and objectives, a better understanding of a diversity of viewpoints and knowledge increase through simulated experience. However, this case brought has also brought a few other benefits.

With these specific settings, this implementation of ComMod comes up with two of the four invariants mentioned on the basis of a comparative analysis of more than twenty cases across the world (Etienne, 2009), the two others still being true, but weaker. These two invariants are the involvement of people and a solid legitimacy of 'commodian'. In the Maehae case, the researcher built the legitimacy of the approach on his name. In the longer term, this increases the level of trust in his propositions.

This case, even with an objective of knowledge increase for the researcher, could provide the basis for joint thinking among community leaders. Information about new ways of collaboration and new knowledge about natural resources management came to villagers and community leaders through the process. Also, repeated and frequent interactions with the researcher allowed the villagers to better know the issues at stake for the researcher. Hence, when they meet these issues, people can ask the researcher to come along suitably.

CHAPTER 7: CONCLUSION

7.1 The Process

It is difficult for the researcher or any other outsider to understand the vague interactions and relationships in a watershed area where resource-conservation laws cannot be straight-forwardly enforced. Through this companion modelling implementation in a complex human-socio-political context, a better understanding of the roles and interactions between local farmers and the forester in the compromised-management arena of the forest is achieved. The role-playing game provided an environment that enhanced and stimulated the players to express and perform the protocols and norms of resource management among communities. Besides this understanding, knowledge and decision-making rules for farming practice could be derived from the game and follow-up interviews. The environment and rule settings in the game allowed the players to observe and learn new knowledge on farm management with regard to markets and prices; some of the players modified and integrated the knowledge gained to improve their farm management. The RPG, which permits the sharing of different representation among participants, raised their concerns and awareness on using and managing resources by multiple actors, and with conflicts of interest. During the RPG sessions implementation, the game could stimulate collective actions that allowed the players to exercise resolving conflict problems and promote collective institutional invention.

The better understanding and verified knowledge obtained from the game session enriched the pre-conceptualization of the system and accompanied the conception and design of the multi-agent based model. In addition to the RPG session, besides the traditional secondary data analysis and field surveys, including interviews, there were a variety of companion tools and methods employed in this. This study shows that, in the context of resource management where the conflict in resources use and management are among local users and between users and state agencies, short-period investigations and/or traditional knowledge inquiry methods are not sufficient to elucidate the reliable detail. RPG is potentially suitable to cope with this context. Scenario visioning allows participants to feel free in expressing the representation of resource management concerns and project the vision in the future. The interaction form among the researcher and the participants, as well as the question set is not restricted. Furthermore, regular field visits and close interactions with participants, in a formal and informal manner, establishes trust and builds a relationship between the researcher and local people, one that significantly supports the research activities. In such a complex social-ecological system, one of the difficulties is elucidating the behavior and strategic decision-making processes of a group of actors, particularly local organizations, in this case, the village network and village committee. Participative observation permits the generation of plausible explanations for the actions and interactions among group members.

The integrative use of role-playing, multi-agent based modeling and participatory simulation is the common posture taken among the ComMod practitioner, in order to achieve knowledge sharing, collective learning and strategic scenarios exploration. However, in the watershed/human-resource-related context where the focus of interest is on conflict resolution, this requires engagement and support from stakeholders at different organizational levels. It is necessary to position the role and interaction of the researcher with local institutions, in order to stimulate and enhance collective action across institutional layers. Furthermore, to ascertain social capital and the rehearsal of adaptive management in the future, co-organization, facilitation, consultation and artifacts support are the main researcher roles. The stakeholders have ownership of the processes and continue the action after termination of the research project.

Through the series of participatory knowledge inquiry and institutional engagement, the adaptive capability is created at the institutional level and extended to the individuals through social networks and functions. The knowledge and findings derived from the field are integrated into the MAS model developed under the Cormas platform. The model design and developments evolve in correspondence with the contingencies arising along the research processes. At present, the model well represents key actors at the individual and institutional level. The main resources are farmland, forest and water; actors or agents in the model who use and manage resources, and this creates consequences and feedback for each person. The main features in the model emphasize the behavior and decision making of the individuals in using resources, as well as the action and interaction between the individuals and the institution. In this model prototype, the spatial features in the model do not represent explicit spatial characteristic of the Maehae; they replicate the spatial setting of the land-forest RPG instead. The bio-physical processes in the model are simplified based on rules and stochastic functions, hydrological dynamics and functions are abstract, while the historical data of crop yields and prices is used to determine farm production in the model.

The different scenarios formulated from the previous activities with the participation and engagement of multi-level stakeholders, were simulated to assess their impacts. The indicators as outputs from the model simulation could then be analyzed to reflect the four main performances of the system, which are water resource condition, farm productivity, economic revenue and the equitability of income distribution. The sensitivity analysis was conducted to assess the influences of different combinations of the selected factors that determine the performance of the modeled system. These factors are functioning of the village network, the level of monitoring, lobbying among the village network committee, and the social network. The simulation data is primarily analyzed using descriptive statistic and an analysis of variance (ANOVA), and then the Univariate Analysis of Variance with a full factorial model is employed to assess the contributing effects of the selected factors to the indicators, which are total cash income,

income distribution, the number of crop failure plots, the number of new plots created, the number of new plots found or monitored, and the number of new plots reclaimed. For the water rule scenario simulation, the effectiveness of water rule emergence is assessed. This scenario exploration and impact assessment suggests that strengthening the village network function and individual engagement in monitoring and water rule development, is important.

7.2 The Contributions and Responses to the Research Questions

Social learning, as a critical pre-requisite to ensure the success of participatory natural resources management, was one pathway to strengthen the adaptive capability of stakeholders and bring resilience to cope with the complex and dynamic social-ecological system. Therefore, this study aimed to engage multiple institutional stakeholders in the process. The MAS model was one of the target tools that encompassed key actors, related resources and the interrelations among them, those that reflect the complexity of the system.

The role-playing game has proved its effectiveness in facilitating the sharing of different points of view among individual participants. This tool also stimulates the collective effort in trying to resolve a problem. The players who participated in the land-forest game sessions expressed the norm of local people and the forester in managing forest resources within the situation of a conflict of interest. This may not have created new knowledge for the players, but it allowed them to see the connection of individual action and the consequences that may have emerged at the whole system level. Likewise, the contribution of the water RPG was mainly for verification of the pre-knowledge of the researcher, and one important lesson given to the players was allowing them to confront and collectively resolve the given problem. This might raise their concerns on the water resource sharing issue, and create awareness on water resource use and conflict.

The RPG could achieve the pre-set objective, targeting the individual level of the stakeholder; however, there is no concrete link between the individual and institutional level. It is common that watersheds in northern Thailand consist of many villages belonging to different ethnic groups scattered across sub-catchments, with farmland located in different locations that cannot be defined by either catchment boundary or village boundary. Thus, with regard to forest and water use and management in the watershed, this farmland scattering characteristic does not correspond to the location setting of common upstream-downstream water management contexts. The knowledge, concerns and awareness that the players obtain from participating in the game, could not be effectively propagated to the community level. The conflict which occurred at one location, although at the village level, was not equally shared by all. Therefore, the RPG was not applied at the village or institutional level. Nevertheless, the equal sharing water scenario suggested in the game, corresponded to the one formulated and the institutional level.

The evolution of the resource management issue from forest to water was not part of the initial research agenda: the Commod approach allows research processes, timeframes and tools to be adjusted and be flexible to cope with this contingency. This did not alter the predefined objective, but it modified the process. The evolution and modification of the problem issue resulted in a change in the tools used and the research process. Thus, this facilitating process and the tools supported social learning and stimulated social concern that finally resulted in alternative resource management behaviors and success in creating rules for water use and management. Although the social awareness on land and water resource management still existed after termination of the research process, the functioning of the village network could not make satisfactory progress to implement the rule sets, due to a lack of authority and strong and continuous support from the government sectors.

In summary, the Commod approach and engagement of local institutions in this study has contributed to pathway building that has allowed and facilitated stakeholders and institutions to engage and participate throughout all of the processes, including problem identification, sharing and improving a common understanding and the knowledge on resource management issues related to the problem, and collective resolution analysis.

7.3 Recommendation and Perspectives

The underlying experiences drawn from this ComMod implementation in a watershed area of northern Thailand, one that contains specific complexity encompassing social, ecological and political issues together, is organized in many respects to suggest improving ComMod practices and addressing key remarks for further implementation to support integrated watershed management .

7.3.1 ComMod Process, Tools and Organization

7.3.1.1 Organizing the Processes

In the complex watershed resource management context, the issues and awareness among stakeholders are dynamic and tend to vary. In this case, the water scarcity arises when a drought occurs and the level of concern of the stakeholders also varies by season. For the social learning and adaptive capability, certain situations are required to develop concern and awareness; therefore, the ComMod process and the implementation timeframe should consider the dependencies with this seasonal determinant.

There are variations among those stakeholders playing important roles in the watershed context, with heterogeneities in the horizontal and vertical space. It is important to involve diverse stakeholders in the ComMod process, in order to inter-exchange ranges of perception and representation in the collective learning process. Institutional analysis should be carried out to ensure the involvement of key stakeholders; however, in the context of watershed management in Thailand, ensuring cooperation among stakeholders at the institutional and administrative levels will be a trade-off with the time and effort required to organize it, as well as balancing participation among stakeholders. Thus, the purposes set for each event should be defined clearly. This can help to determine the type of stakeholder to be included.

Trust building is an essential element that can ease the process and ensure stakeholder participation, plus insight and reliable information. This requires regular visits and the participation of the researcher in local events and collective action. Thus, this might prolong the research time frame and conflict with any limited budget allowed. Providing monetary support is sometimes needed to compensate for the cost of participation times; however, this may distract or provoke misinterpretation at the participation level of the stakeholder. In addition, recruiting supporting field staff responsible for field work from local people, those who often interact with the stakeholder, can help merge the relations gap and build trust between the research project and stakeholders. The staff also hold the status of local stakeholder, thus this will be an additional outcome.

Institutional engagement is crucial for participatory modeling of watershed management problems related to conflicts of interest, and calls for engagement and movement beyond the individual level. Finally, the organization and implementation of ComMod demands a number of facilitating staff to carry on participatory activities which are costly and time consuming. It calls for maintaining a group of staff members; in practice, the ComMod is a lengthy process by nature, thus the process organization strategy should be aware of this uncertainty and the constraints.

7.3.1.2 Method and Tools (Role-playing game, MABM and companion tools)

On the one hand, there is no question of the effectiveness of role-playing when integrated into the ComMod process, but on the other hand it is still costly, staff and time consuming. A common limitation is the limited number of participants who can be involved in the process, and the dissemination of the learning and experiences into the broader scale. Due to the multiple objectives expected from the game, choosing participants to serve all the objectives is difficult. Thus, RPG organizing should balance and prioritize the objectives set, thus determining participant selection. A hybrid computerized RPG that is portable, to be played by a greater number of participants, was tried in this study; however, this advantage was still overridden by inviting participants. Uncertainties may arise with regards to the game organization drawn from this study; uncertainties that should be of concern are the absence of invited players and electricity blackouts. Thus, be aware to observe the study area and the tendency of these occurrences, and be well prepared in advance.

A multi-agent based model is one of the common outputs from a ComMod process, and can be used for participatory simulation with stakeholders. The model is designed to have abstract representation, requires from the stakeholder user experience through being involved in the co-design and development processes. Thus, it may not be comfortably applied to other non-experienced users, especially when problem evolving exists and the set of participants is modified. For less complex human-environment interaction representations, alternative, non-computerized models and simulation tools can be applied instead, such as maps and map overlays, scenario storytelling, and image animations illustrating simple spatial dynamic simulations and diagrams.

7.3.1.3 Social Network and Social Power

Social networks and structures are important features within watershed management in terms of information dissemination and improving the impact from ComMod participatory actions. Social power needs to be explored to identify the key leader crucial to the negotiation process. Prior to conducting such a collective workshop, the advantages and disadvantages as well as the trade-off of bringing different social-powers to meet needs to be anticipated. This will be elaborated upon further in the researcher position and role section.

7.3.1.4 Researcher Positioning

What role should the researcher play within the ComMod process? In general, participating in social and cultural events can help develop trust between the researcher and stakeholders. In particular, for participating in social movements, the role of the researcher should as a facilitator and co-organizer of the collective action. Thus, the stakeholders hold a sense of belonging to the action and efforts, helping to improve the degree of concern and engagement, something that improves their adaptive capability and ensure the sustenance of this social capital. Another aspect we should bring into consideration is dealing with different social power groups, where a neutral position is important to build trust and good relations with all the groups. Ignorance of this may create negative effects or cause a failure of collective workshop organization and consecutive activities.

7.3.2 Integrated Watershed Management

It is acknowledged that state laws and regulations imposed on watershed management in Thailand face difficulties in practice, the more control the more complex the matter becomes. There have been a number of participatory modelling approaches implemented and explored to mitigate management problems and conflicts in the watershed context, ending with perspectives and remarks addressing stakeholder selection, supporting tools that facilitate processes of common representation sharing and collective learning; stimulating them to engage in the process. The performance of both human well-being and watershed resources is the result of individual actions and interactions according to each representation. Employing a companion modeling process, especially a role-playing game, has a potential influence on changes in perception and action. If the effect is limited at the individual level; it has even less impact at the whole watershed system level. Multi-institutional organs need to engage in these adaptive capability building processes. In addition, a watershed is trans-boundary resources management; local key components and their interactions are inevitably linked to exogenous factors. Therefore, to achieve natural resource management in the watersheds of northern Thailand, institutional frameworks and policy incentives (support from institutions) at the higher level are needed, but it would be a trade-off with time and effort to organize this, and it might interfere with or decrease the participation of local stakeholders. Social participation and learning should be implemented prior to this step, to feed a bottom-up "democratic learning" process. Lastly, the ComMod process set and employed in this case study may not be directly applied for out-scaling the effects and impacts into other areas, though it provides a promising pathway and highlights the key concerns for implementation in other watersheds in Thailand, and other areas that have a similar social, ecological and political context

REFERENCES

AGARWAL C., GREEN G.M., GROVE J.M., EVANS T., SCHWEIK C. Are view and assessment of land-use change models: dynamics of space, time, and human choice? USDA Forest Service Northeastern Forest Research Station Publication NE-297, 2002. Available online at: http://www.fs.fed.us/ne/newtown_square /publications/technical_reports /pdfs/2002/gtrne297.pdf

AN L., BROWN D.G. Survival analysis inland-change science: integrating with GIS and remote sensing in Southeastern Michigan. *Annals of Association of American Geographers*, 2008, vol.98 (2), p. 323-344.

ARTHUR B.W. Inductive reasoning and bounded rationality. *The American Economic Review*, 1994, vol. 84 (2), p. 406–411.

AXELROD R.M., COHEN M.D. Harnessing Complexity: Organizational Implications of a Scientific Frontier. New York: Basic Books, 2000, 208 p.

BACIC I.L.Z., ROSSITER D.G., BREGT A.K. Using spatial information to improve collective understanding of shared environmental problems at watershed level. *Landscape and Urban Planning*, 2006, vol.77 (1-2), p. 54-66.

BARNAUD C., BOUSQUET F., TRÉBUIL G. Multi-agent simulations to explore rules for rural credit in a highland farming community of Northern Thailand. *Ecological Economics*, 2008, vol.66 (4), p. 615-627.

BARNAUD C., PROMBUROM T., TRÉBUIL G., BOUSQUET F. An evolving simulation/gaming process to facilitate adaptive watershed management in northern mountainous Thailand. *Simulation & Gaming*, 2007, vol.38 (3), p. 398-420.

BARRETEAU O. The joint use of role-playing games and models regarding negotiation processes: characterization of associations. *Journal of Artificial Societies and Social Simulation*, 2003a, vol. 6 (2). Available online at: http://jasss.soc.surrey.ac.uk/6/2/3.html

BARRETEAU O., GARIN P., DUMONTIER A., ABRAMI G., CERNESSON F. Agent-Based Facilitation of Water Allocation: Case Study in the Drome River Valley. *Group Decision and Negotiation*, 2003b, vol. 12 (5), p. 441-461.

BATO V.A. Determining of Major Factors Affecting the Land Use/Land Cover of upper Magat watershed - a preliminary study for the land Use/Land Cover Change Case Study of Upper Magat Watershed Phase - II. *The 21st Asian Conference on Remote Sensing*, December 4-8, 2000, Taipei, Taiwan, 2000.

BECU N., BOUSQUET F., BARRETEAU O., PEREZ P., WALKER B. A Method for Eliciting and Modeling Stakeholders' Representations with Agent Based Modeling. In: *Multi-Agent-Based Simulation III: 4th International Workshop, MABS 2003*, Melbourne, Australia, July 14, 2003, Revised Papers. D. HALES, B. EDMONDS, E. NORLING, J. ROUCHIER (Eds.). Heidelberg : Springer Berlin, 2003, p. 131-148.

BECU N., NEEF A., SCHREINEMACHERS P., SANGKAPITUX C. Participatory computer simulation to support collective decision-making: Potential and limits of stakeholder involvement. *Land Use Policy*, 2008, vol.25 (4), p. 498-509.

BERGER T. Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes, and policy analysis. *Agricultural Economics*, 2001, vol. 25 (2–3), p. 245–260.

BERGER T., SCHREINEMACHER S.P. Creating agents and landscapes for multi agent systems from random samples. *Ecology and Society*, 2006, vol. 11 (2). Available online at: URL: http://www.ecologyandsociety.org/vol11/iss2/art19/

BHARWANI S., BITHELL M., DOWNING T.E., NEW M., WASHINGTON R., ZIERVOGEL G., Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. *Philosophical Transactions of the Royal Society B*, 2005, vol. 360, p. 2183–2194.

BLOMQUIST W., SCHLAGER E. Political Pitfalls of Integrated Watershed Management. *Society & Natural Resources*, 2005, vol.18 (2), p.101-117.

BODIN O., CRONA B., ERNSTSON H. Social Networks in Natural Resource Management: What Is There to Learn from a Structural Perspective? *Ecology and Society*, 2006, vol. 11 (2). Available online at: http://www.ecologyandsociety.org/vol11/iss2/resp2/

BOISSAU S., CASTELLA J.C. Constructing a common representation of local institutions and land use systems through simulation-gaming and multi-agent modeling in rural areas of northern Vietnam: "The SAMBA-week methodology." *Simulation & Gaming*, 2003, vol. 34 (3), p. 342-357.

BOOCH G., RUMBAUGH J., JACOBSON I. *The Unified Modeling Language User Guide*. Addison-Wesly, 1999, 482 p.

BORRINI-FEYERABEND G., FARVAR M.T., NGUINGUIRI J.C., NDANGANG V.A. *Co-management of Natural Resources: Organising, Negotiating and Learning-by-Doing*. GTZ and IUCN. Heidelberg, Germany : Kasparek Verlag, 2000, 123 p.

BOUSQUET F., BARRETEAU O., LE PAGE C., MULLON C., WEBER J. An environmental modelling approach: The use of multi-agent simulations. In: *Advances in environmental and ecological modeling*. F. BLASCO, A. WEILL (Eds.). Elsevier, 1999, p. 113-122.

BOUSQUET F., TRÉBUIL G. Introduction to companion modeling and multi agent systems for integrated natural resource management in Asia. In: *Companion Modeling and Multi-Agent Systems for Integrated Natural Resource Management in Asia,* B. HARDY, F. BOUSQUET, G. TRÉBUIL (Eds.). Los Banos, Philippines : International Rice Research Institute (IRRI), 2005, p. 1-17.

BROWN D.G., ROBINSON D.T. Effects of heterogeneity in preferences on an agent-based model of urban sprawl. *Ecology and Society*, 2006, vol. 11 (1). Available online at: http://www.ecologyandsociety.org/vol11/iss1/art46/.

BROWN D.G., ROBINSON D.T., AN L., NASSAUER J.I., ZELLNER M., RAND W., RIOLO R., PAGE S.E., LOW B., WANG Z. Exurbia from the bottom-up: Confronting empirical challenges to characterizing a complex system. *Geoforum*, 2008, vol. 39 (2), p. 805-818.

BROWN D.G., WALKER T., MANSON S., SETO K. Modeling land use and land cover change. In: *Land Change Science: Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface*, G. GUTMAN, A.C. JANETORS,

C.O. JUSTICE, E.F. MORAN, J.F. MUSTARD, R.R., RINDFUSS, D.L. SKOLE, B.L. TURNER, M.A. COCHRANE (Eds). New York : Springer. 2004, p. 395-409.

BULL R., PETTS J., EVANS J. Social learning from public engagement: dreaming the impossible. *Journal of Environmental Planning and Management*, 2008, vol. 51 (5), p. 701-716.

CAMERER C.F. *Behavioral Game Theory: Experiments in Strategic Interaction*. Princeton, NJ : Princeton University Press, 2003. 544 p.

CAMINITI J.E. Catchment modelling — a resource manager's perspective. *Environmental Modelling & Software*, 2004, vol. 19 (11), p. 991-997.

CARDENAS J.C., OSTROM E. What do people bring in to the game? Experiments in the field about cooperation in the commons. *Agricultural Systems*, 2004, vol. 82 (3), p. 307–326.

CARDENAS J.C., STRANLUND J., WILLIS C. Local environmental control and institutional crowding-out. *World Development*, 2000, vol. 28 (10), p. 1719–1733.

CARUSO G., ROUNSEVELL M., COJOCARU G. Exploring a spatio-dynamic neighbourhood-based model of residential behavior in the Brussels periurban area. *International Journal of Geographical Information Science*, 2005, vol. 19 (2), p. 103–123.

CASE A. Neighborhood influence and technological change. *Regional Science and Urban Economics*, 1992, vol. 22, p.491–508.

CASTELLA J.C., KHAM S.P., QUANG D.D., VERBURG P.H., HOANH C.T. Combining top-down and bottom-up modelling approaches of land use / cover change to support public policies: Application to sustainable management of natural resources in northern Vietnam. *Land Use Policy*, 2007, vol. 24 (3), p. 531-545.

CASTILLO D., SAYSEL A.K. Simulation of common pool resource field experiments: a behavioral model of collective action. *Ecological Economics*, 2005, vol. 55 (3), p. 420–436.

COUCLELIS H. A theoretical framework for alternative models of spatial decision and behavior. *Annals of the Association of American Geographers*, 1986, vol. 76 (1), p. 95–113.

D'AQUINO P., LE PAGE C., BOUSQUET F. The SelfCormas Experiment: Aiding Policy and Land-Use Management by Linking Role-Playing Games, GIS, and ABM in the Senegal River Valley. In: *Agent-Based Models of Land-Use and Land-Cover Change: Report and Review of an International Workshop, October 4-7, 2001, Irvine, California, USA*. D.C. PARKER, T. BERGER, S.M. MANSON (Eds). LUCC Report Series No.6, 2002 p. 70-72.

D'AQUINO P., LE PAGE C., BOUSQUET F., BAH A. Using Self-Designed Role-Playing Games and a Multi-Agent System to Empower a Local Decision-Making Process for Land Use Management: The SelfCormas Experiment in Senegal. *Journal of Artificial Societies and Social Simulation*, 2003, vol. 6 (3). Available online at: http://jasss.soc.surrey.ac.uk/6/3/5.html

DIETZ T., OSTROM E., STERN P.C. The Struggle to Govern the Commons. *Science*, 2003, vol. 302 (5652), p. 1907-1912.

DEADMAN P.J. Modelling individual behavior and group performance in an intelligent agent-based simulation of the tragedy of the commons. *Journal of Environmental Management*, 1999, vol. 56, p. 159–172.

DEADMAN P.J., ROBINSON D.T., MORAN E., BRONDIZIO E. Colonist household decision making and land use change in the Amazon Rainforest: an agent-based simulation. *Environment and Planning B: Planning and Design*, 2004, vol. 31 (5), p. 693–709.

DEARDEN P. Integrated watershed management planning and information requirements in northern Thailand. *Can. J. Dev. Stud.*, 1996, vol. XVII, p.1-17.

DEFFUANT G., HUET S., AMBLARD F. An individual-based model of innovation diffusion mixing social value and individual benefit. *American Journal of Sociology*, 2005, vol. 110 (4), p. 1041–1069.

DE GROOT W.T. Environmental Science Theory: Concepts and Methods in a One-World Problem Oriented Paradigm. Amsterdam and New York : Elsevier Science Publishers, 1992. 584 p.

DORAN J. Intervening to Achieve Co-operative Ecosystem Management: Towards an Agent Based Model. *Journal of Artificial Societies and Social Simulation*, 2001, vol.4 (2), p.1-20. Available online at: http://jasss.soc.surrey.ac.uk/4/2/4.html

DUFFY J. Agent-based models and human-subject experiments. In: *Handbook in Agent-Based Computational Economics*, L. TESFATSION, K. JUDD (Eds). New York : Elsevier, 2006, p. 949-1011.

EKASINGH B., NGAMSONSUKE K. Searching for simplified farmers' crop choice models for integrated watershed management in Thailand: A data mining approach. *Environmental Modelling & Software*, 2009, vol.24 (12), p. 1373-1380.

EKASINGH M., SAMRANPONG C., WEERAJIT W. Land Use and Cover Changes Detection in Maehae and Nong Hoi. In: *Annual Academic Conference 2001*, The Royal Project Foundation, 2001, p. 286-307.

EMERSON K., GERLAK A., BARRETEAU O., BRINK M., FARAHBAKHSHAZAD N., MORRISON G. PROMBUROM P. A Framework to Assess Collaborative Governance: A New Look at Four Water Resource Management Cases. Paper presented at the *2009 Amsterdam Conference on the Human Dimensions of Global Environmental Change*, 2-4 December 2009. Available online at: http://www.earthsystemgovernance.org /ac2009/papers/AC2009-0441.pdf

ENTERS T. The economics of land degradation and resource conservation in northern Thailand: challenging the assumptions. In: *Counting the costs: economic growth and environmental change in Thailand*. J. RIGG (Ed.). Singapore : Institute of South East Asian Studies, 1995, p. 90-110.

ETIENNE M.

EVANS T.P., SUN W., KELLEY H. Spatially explicit experiments for the exploration of land use decision-making dynamics. *International Journal of Geographic Information Science*, 2006, vol. 20 (9), p. 1013–1037.

FERREYRA C., DE LOE R.C., DREUTZWISER R.D. Imagined communities, contested watersheds: Challenges to integrated water resources management in agricultural areas. *Journal of Rural Studies*, 2008, vol.24 (3), p. 304-321.

FEUILLETTE S., BOUSQUET F., LE GOULVEN P. SINUSE: a multi-agent model to negotiate water demand management on a free access water table. *Environmental Modelling & Software*, 2002, vol. 18 (5), p. 413-427.

FAO. *Land-water linkages in rural watersheds*. Rome, Italy : FAO, FAO Land and Water Bulletin 9, 2002, 90p.

FAO. *The new generation of watershed management programmes and projects*. Rome, Italy : FAO, FAO Forestry Paper150, 2006, 131p.

FORESTER J. The deliberative practitioner: Encouraging participatory planning processes. Cambridge, MA. : MIT Press, 1999, 321 p.

FOWLER M., SCOTT K. *UML Distilled: Applying the Standard Object Modeling Language*. New York : Columbia University Press, 1999, 163 P.

GANJANAPAN A. The politics of conservation and the complexity of local control of forests in the northern Thai highlands. *Mountain research and development*, 1998, vol.18 (1), p. 71-82.

GANJANAPAN A. Indigenous and scientific concepts of forest and land classification in northern Thailand. In: *Seeing Forests for Trees: Environment and Environmentalism in Thailand*, P. HINSCH (Ed.). Chiang Mai, Thailand : Silkworm Books, 1996, p. 247-267.

GERMAN L., MANSOOR H., ALEMU G., MAZENGIA W., AMEDE T., STROUD A. Participatory integrated watershed management: Evolution of concepts and methods in an ecoregional program of the eastern African highlands. *Agricultural Systems*, 2007, vol.94 (2), p. 189-204.

GILBERT N., TROITZSCH K.G. *Simulation for the Social Scientist*. Second edition. Columbia University Press, Open University Press, 2005, p. 1-273.

GILLOGLY K. Developing the "Hill Tribes" of Northern Thailand. In: *Civilizing the Margins: Southeast Asian Government Policies for the Development of Minorities*, C.R. DUNCAN (Ed). Cornell University Press, 2004, p. 116-149.

GIMBLETT H.R. Integrating Geographic Information Systems and Agent-based Modeling Techniques for Simulating Social and Ecological Processes. Oxford University Press, 2002, p.1-344.

GOLDSTONE R.L., JONES A., ROBERTS M. Group path formation. IEEE Transactions on System, Man, and Cybernetics. *Part A Systems and Humans*, 2006, vol. 36 (3), p. 611–620.

GRAVERS M. Ethnic Minorities in Thailand - Figures and selected Biography. In: *Forest in Culture - Culture in Forest. Research Center on Forest and People in Thailand*, E. POULSEN, F. SHOV, S. LAKANAVICHIAN, S. THAINISAWANYANGKURA, H. BORGTOFT, O. HOIRIS (Eds.). Danish Institute of Agricultural Science, Research Centre Foulum, International Unit, P.O.Box50, DK-8830 Tjele, Denmark, 2001, p. 17-20.

GRIMM V., BERGER U., BASTIANSEN F., ELIASSEN S., GINOT V., GISKE J., GOSS-CUSTARD J., GRAND T., HEINZ S.K., HUSE G., HUTH A., JEPSEN

J.U., JORGENSEN C., MOOIJ W.M., MULLER B., PE'ER G., PIOU C., RAILSBACK S.F., ROBBINS A.M., ROBINS M.M., ROSSMANITH E., RUGER N., STAND E., SOUISSI S., STILLMAN R.A., VABO R., VISSER U., DEANGELIS D.L. A standard protocol for describing individual-based and agent-based models. *Ecological Modelling*, 2006, vol.198, p. 115-126.

GRIMM V., REVILLA E., BERGER U., JELTSCH F., MOOIJ W.M., RAILSBACK S.F., THULKE H.H., WEINER J., WIEGAND T., DEANGELIS D.L. Pattern-oriented modeling of agent-based complex systems: lessons from ecology. *Science*, 2005, vol. 310 (5750), p. 987–991.

GROSH M., GLEWWE P. Designing Household Survey Questionnaires for Developing Countries: Lessons From 15 Years of the Living Standards Measurement Study, Vols.1–3. Washington, DC: World Bank, 2000.

GURUNG T.R., BOUSQUET F., TRÉBUIL G. Companion modeling, conflict resolution, and institution building: sharing irrigation water in the Lingmuteychu Watershed, Bhutan. *Ecology and Society*, 2006, vol. 11 (2), p. 1-36.

HALES D., ROUCHIER J., EDMONDS B. Model-to-Model Analysis. *Journal of Artificial Societies and Social Simulation*, 2003, vol.6 (4). Available online at: http://jasss.soc.surrey.ac.uk/6/4/5.html

HAPPE K. Agricultural policies and farm structures: agent-based modelling and application to EU policy reform. Studies on the Agricultural and Food Sector in Central and Eastern Europe. *IAMO*, 2004, vol. 30. Available online at: http://www.iamo.de/dok/sr_vol30.pdf

HARE M., LETCHER R., JAKEMAN A.J. Participatory modelling in natural resource management: comparison of four case studies. *Integrated Assessment*, 2003, vol. 4 (2), p. 62-72.

HASTINGS P., BOONRAKSA C. Integrated information for natural resouRces management: Supplementary report for TDRI Year-end Conference, Industrializing Thailand and its Impact on the Environment. Thailand Development Research Institute, Bangkok, 1990.

HEATHCOTE I.W. *Integrated Watershed Management: Principle and Practice*. United States of America : John Wiley & Sons, Inc., 1998, 414 p.

HENRICH J., BOYD R., BOWLES S., CAMERER C., FEHR E., GINTIS H. Foundations of Human Sociality: Economic Experiments and Ethnographic Evidence from Fifteen Small-Scale Societies. Oxford: Oxford University Press, 2004.

HOARE P. The role of extension: A northern Thailand watershed case study. In: *Watershed resources management: An integrated framework with studies from Asia and the Pacific*. Boulder, CO : Westview Press, 1986, p. 159-175.

HOLLAND J.H. *Hidden Order: How Adaptation Builds Complexity*. Cambridge, MA : Perseus Books, 1995, 208 p.

HOLLING C.S. *Adaptive environmental assessment and management*. London : John Wiley, 1978, 377 p.

HSIAO C. *Analysis of Panel Data. Economic Society Monographs No.11*. Cambridge, UK : Cambridge University Press, 1986, 256 p.

HUIGEN M.G.A. First principles of the MameLuke multi-actor modeling framework for land use change, illustrated with a Philippine case study. *Journal of Environmental Management*, 2004, vol. 72, p. 5–21.

HUIGEN M.G.A., OVERMARS K.P., DEGROOT W.T. Multi-actor modeling of settling decisions and behavior in San Mariano watershed, the Philippines: a first application with the MameLuke framework. *Ecology and Society*, 2006, vol. 11 (2). Available online at: http://www.ecologyandsociety.org/vol11/iss2/art33/

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE (IFPRI). *Datasets*, 2005. Available online at: http://www.ifpri.org/data/dataset.asp

IRWIN E.G., BOCKSTAEL N.E. Interacting agents, spatial externalities and the evolution of residential land use patterns. *Journal of Economic Geography*, 2002, vol. 2(1), p. 31–54.

ISAGER L. History and People of North Thailand. In: *Forest in Culture - Culture in Forest. Research Center on Forest and People in Thailand*, E. POULSEN, F. SHOV, S. LAKANAVICHIAN, S. THAINISAWANYANGKURA, H. BORGTOFT, O. HOIRIS (Eds.). Tjele, Denmark : Danish Institute of Agricultural Science, Research Centre Foulum, International Unit, P.O.Box50, DK-8830 Tjele, Denmark, 2001, p. 85-115.

JAGER W., JANSSEN M.A. Using artificial agents to understand laboratory experiments of common-pool resources with real agents. In: *Complexity and Ecosystem Management: The Theory and Practice of Multi-Agent Systems*, M.A. JANSSEN (Ed.). Cheltenham : Edward Elgar Publishers, 2002, p. 75–102.

JANSSEN M.A. Complexity and Ecosystem Management: The theory and practice of multi-gent systems. Cheltenham, UK; Northamton, MA, USA. : Edward Elgar, 2002, 344 p.

JANSSEN M.A., AHN T.K. Learning, signaling and social preferences in public good games. *Ecology and Society*, 2006, vol. 11 (2). Available online at: http://www.ecologyandsociety.org/vol11/iss2/art21/

JANSSEN M.A., OSTROM E. Empirically Based, Agent-based models. *Ecology and Society*, 2006, vol. 11 (2). Available online at: http://www.ecologyandsociety.org /vol11/iss2/art37/

JESSEL B., JACOBS J. Land use scenario development and stakeholder involvement as tools for watershed management within the Havel River Basin. *Limnologica - Ecology and Management of Inland Waters*, 2005, vol.35 (3), p. 220-233.

JOSHI N.N., OSTROM E., SHIVAKOTI G.P., LAM W.F. Institutional opportunities and constraints in the performance of farmer-managed irrigation systems in Nepal. Asia-Pacific Journal of Rural Development, 2000, 10 (2): p. 67-92.

KRAFT S.E., LANT C.L., ADAMS J., BEAULIEU J., BENNETT D., DURAM L., RUHL J.B. Understanding the Social Context for Ecological Restoration in Multiple-owned Watersheds: The Case of the Cache River, Illinois. U.S. CSREES project number: ILLZ-99E-0151. 1999—2002, Department of Agriculture, NSF/EPA/USDA Water and Watersheds Program, 1999.

LAKANAVICHIAN S. *Forest Policy and History in Thailand*. Faculty of Natural Sciences, University of Aarhus, Research Centre on Forest and People in Thailand, 2001, 63 p.

LAL P., LIM-APPLEGATE H., SCOCCIMARRO M. The Adaptive Decision-Making Process as a Tool for Integrated Natural Resource Management: Focus, Attitudes, and Approach. *Conservation Ecology*, 2002, vol.5 (2), p. 1-11.

LANINI S., COURTIS N., GIRAUD F., PETI V., RINAUDO J.D. Socio-hydrosystem modelling for integrated water-resources management-the Hérault catchment case study, southern France. *Environmental Modelling & Software*, 2004, vol. 19 (11), p. 1011-1019.

LANSING J.S., KREMER J.N. Emergence Properties of Balinese Water Temple Networks: Coadaptation on a Rugged Fitness Landscape. *American Anthropologist*, 1993, vol.95 (1), p. 97-114.

LAUNGARAMSRI P. The ambiguity of "watershed": the politics of people and conservation in northern Thailand. *Sojourn*, 2000, vol.15 (2), p. 153-174.

LE PAGE C., ETIENNE M., BOUSQUET F. Using Dynamics Spatial Entities in Agent-Based Simulations. In: MODSIM 2001 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2001, F. GHASSEMI, M. MCALEER, L. OXLEY, M. SCOCCIMARO (Eds.). 2001, p. 1129-1134.

LEBEL L. Institutional Dynamics and Interplay: Critical Processes for Forest Governance and Sustainability in the Mountain Regions of Northern Thailand. In: *Global Change and Mountain Regions: An Overview of Current Knowledge.* Berlin : Springer-Verlag, 2005, p. 531-540.

LETCHER R.A., CROKE B.F.W., JAKEMAN A.J., MERRITT W.S., PEREZ P. IWRAM: An integrated modelling toolbox for considering impacts of development and land use change in Northern Thailand. In: *Proceedings International Environmental Modelling and Software Society (iEMSs) Conference, Lugano, Switzerland, 24-27 June 2002*. A.E. RIZZOLI, A.J. JAKEMAN (Eds), 2002, p. 97-102.

LIANG Y. From use cases to classes: a way of building object model with UML. *Information and Software Technology*, 2003, vol.45, p. 83-93.

LIVERMAN D., MORAN E.F., RINDFUSS R.R., STERN P.C. *People and Pixels: Linking Remote Sensing and Social Science*. Washington DC: National Academy Press, 1998.

LUBELL M., FULTON A. Local Policy Networks and Agricultural Watershed Management. *Journal of Public Administration Research and Theory*, 2008, vol.18 (4), p. 673-696.

LUBELL M., SCHNEIDER M., SCHOLZ J.T., METE M. Watershed Partnerships and the Emergence of Collective Action Institutions. *American Journal of Political Science*, 2002, vol. 46, (1), p. 148-163.

LUO Y., ZHANG M. Management-oriented sensitivity analysis for pesticide transport in watershed-scale water quality modeling using SWAT. *Environmental Pollution*, 2009, vol.15 (12), p. 3370-3378.

MAKAREWICZ J. Nonpoint source reduction to the nearshore zone via watershed management practices: Nutrient fluxes, fate, transport and biotic responses --- Background and objectives. *Journal of Great Lakes Research*, 2009, vol.35, p. 3-9.

MARCH J.G. Exploration and exploitation in organizational learning. *Organizational Science*, vol. 2 (1), 1991, p. 71–87.

MERTENS B., LAMBIN E.F. Land-cover change trajectories in southern Cameroon. *Annals of the Association of the American Geographers*, 2000, vol. 90, p. 467–494.

MIETTINEN R., VIRKKUNEN J. Epistemic objects, Artefacts and Organizational Change. *Organization*, 2005, vol.12 (3), p. 437-456.

MISSINGHAM B. *Participatory Development in Thailand: A Review of Some Relevant Literature*. ICAM Working Paper 2000/01. Integrated Water Resources Assessment and Management (IWRAM) Framework Project, 2001, 45 p.

MONTEIRO. Does social capital improve watershed environmental governance? In: *Coordinations hydrauliques et justices sociales*. A. RICHARD, P. CARON, J.Y. JAMIN, T. RUF (Eds). Actes du séminaire, novembre 2004, Montpellier, France. Cirad, Montpellier France, Colloques, 2006.

NEEF A. Lost in translation: The participatory imperative and local water governance in North Thailand and Southwest Germany. *Water Alternatives*, vol. 1 (1), p. 89-110.

NEWMAN L., DALE. A. Network structure, diversity, and proactive resilience building: a response to Tompkins and Adger. *Ecology and Society*, 2005, vol.10 (1). Available online at: http://www.ecologyandsociety.org/vol10/iss1/resp2/

OSTROM E. Governing the commons: The evaluation of institutions for collective action. Cambridge University Press. 1994. 285p.

OSTROM E. A behavioral approach to the rational choice theory of collective action. *American Political Science Review*, 1998, vol. 92 (1), p. 1–22.

PAHL-WOSTL C., CRAPS M., DEWULF A., MOSTERT E., TABARA D., TAILIEU T. Social Learning and Water Resources Management. *Ecology and Society*, 2007, vol.12 (2). Available online at: http://www.ecologyandsociety.org/vol12/iss2/art5/

PARKER D.C., BERGER T., MANSON S.M. (Eds). *Agent-based Models of Land use and Land cover Change*. LUCC Report Series 6 (Louvain-la-Neuve: LUCC International Project Office), 2002. Available online at: http://www.indiana.edu/~act/focus1/ABM_Report6.pdf

PARKER D.C., BROWN D.G., POLHILL J.G., MANSON S.M., DEADMAN P.J. Illustrating a new ‘conceptual design pattern’ for agent-based models and land use via five case studies: the MRPOTATOHEAD framework. In: *Agent-based Modelling in Natural Resource Management*. A.L. PAREDES, C.H. IGLESIAS (Eds). Valladolid, Spain : Universidad de Valladolid, 2008. p. 29-62.

PARKER D.C., MANSON S.M., JANSSEN M.A., HOFFMANN M.J., DEADMAN P. Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review. *Annals of the Association of American Geographers*, 2003, vol.93 (2), p. 316-337.

PARKER D.C., MUNROE D.K. The geography of market failure: edge effect externalities and the location and production patterns of organic farming. *Ecological Economics*, 2007, vol. 60 (4), p. 821–833.

PATTANAKIET S., TANGTHAM N. *The 2005 Revised Criteria and Methods in Watershed classification and Mapping*. Paper prepared for The International Training Course in Integrated Watershed Management, Cooperatively organized by TICA and Department of Conservation Faculty of Forestry, Kasetsart University, November 14, 2006.

PEREIRA, H.C. Policy and practice in the management of tropical watersheds. Boulder, CO : Westview Press, 1989, 237 p.

POOMA R., BARFOD A. Vegetation Types of Northern Thailand. In: *Forest in Culture - Culture in Forest. Research Center on Forest and People in Thailand*. E. POULSEN, F. SHOV, S. LAKANAVICHIAN, S. THAINISAWANYANGKURA, H. BORGTOFT, O. HOIRIS (Eds.). Tjele, Denmark : Danish Institute of Agricultural Science, Research Centre Foulum, International Unit, P.O.Box50, DK-8830 Tjele, Denmark, 2001, p. 11-15.

PRAGTONG K., THOMAS D. Evolving Management Systems in Thailand. In: *Keepers of the forest: Land Management Alternatives in Southeast Asia*. M. POFFENBERGER (Ed), Quezon city, Manila : Ateneo de Manila University Press, 1990, p. 167-187.

PUGINIER O. Hill tribes struggling for a land deal: Participatory land use planning in northern Thailand amid controversial policies. Ph.D. dissertation, Universitat zu Berlin, 2002, 151 p.

RAO N.S., EASTON Z.M., SCHNEIDERMAN E.M., ZION M.S., LEE D.R., STEENHUIS T.S. Modeling watershed-scale effectiveness of agricultural best management practices to reduce phosphorus loading. *Journal of Environmental Management*, 2009, vol.90 (3), p. 1385-1395.

RERKASEM K., RERKASEM B. *Shifting Cultivation in Thailand: Its Current Situation and Dynamics in the Context of Highland Development*. 2nd edn. London, England : International Environment and Development, 1994. 31 p.

RESCHKE C.H. Evolutionary perspectives on simulations of social systems. *Journal of Artificial Societies and Social Simulation*, 2001, vol. 4. Available online at: http://jasss.soc.surrey.ac.uk/4/4/8.html

ROBINSON D.T., BROWN D.G., PARKER D.C., SCHREINEMACHERS P., JANSSEN M.A., HUIGEN M., WITTMER H., GOTTS N., PROMBUROM P., IRWIN E., BERGER T., GATZWEILER F., BARNAUD C. Comparison of empirical methods for building agent-based models in land use science. *Journal of Land Use Science*, 2007, vol.2 (1), p. 31-55.

ROYAL FOREST DEPARTMENT. *Forest Area in Thailand*. 1998. 48 p.

ROYAL PROJECT FOUNDATION. *The Peach and the Poppy: The story of Thailand's Royal Project*. Bangkok, Thailand : Allied Printers, 2007, 280 p.

SATO J. Public Land for the People: The Institutional Basis of Community Forestry in Thailand. *Journal of Southeast Asian Studies*, 2003, vol.34 (2), p. 329-346.

SCHNEIDER M., SCHOLZ J., LUBELL M., MINDRUTA D., EDWARDSEN M. Building Consensual Institutions: Networks and the National Estuary Program. *American Journal of Political Science*, vol.47 (1), p. 143-158.

SCHOLZ J.T., WANG C.L. Cooptation or Transformation? Local Policy Networks and Federal Regulatory Enforcement. *American Journal of Political Science*, 2006, vol. 50 (1), p. 81-97.

SCHREINEMACHERS P. The (Ir-)Relevance of the Crop Yield Gap Concept to Food Security in Developing Countries. With an Application of Multi-Agent Modeling to Farming Systems in Uganda. Cuvillier Verlag Gottingen : University of Bonn Dissertation, 2006. Available online at: http://hss.ulb.uni-bonn.de/diss_online /landw_fak/2006/schreinemachers_pepijn

SCHREINEMACHERS P., BERGER T. Land-use decisions in developing countries and their representation in multi-agent systems. *Journal of Land Use Science*, 2006, vol.1 (1), p. 29–44.

SCHUESSLER A.A. Ecological inference. *Proceedings of the National Academy of Sciences*, 1999, vol. 96, p. 10,578–10,581.

SCOCCIMARRO M., WALKER A., DIETRICH C., SCHREIDER S., JAKEMAN T., ROSS H. A framework for integrated catchment assessment in northern Thailand. *Environmental Modelling & Software*, 1999, vol.14, p. 567-577.

SEONG L.K., CHUNG E.S., KIM Y.O. Integrated watershed management for mitigating streamflow depletion in an urbanized watershed in Korea. *Physics and Chemistry of the Earth, Parts A/B/C*, 2008, vol.33 (5), p. 382-394.

SETO K.C., KAUFMANN R.K. Modeling the drivers of urban land-use change in the Pearl River Delta, China: integrating remote sensing with socio-demographic data. *Land Economics*, 2003, vol. 79 (1), p. 106–121.

SONCINI-SESSA R., CASTELLETTI A., Weber E. A DSS for planning and managing water reservoir systems. *Environmental Modelling & Software*, 2003, vol. 18 (5), p. 395-404

STRAUSS A., CORBIN J. Basics of Qualitative Research: Grounded Theory Procedures and Techniques. Newbury Park, CA : Sage Publications, 1990.

TANGTHAM N. Watershed Classification: *The Macro Land-use Planning for the* Sustainable *Development of Water Resources*. Paper presented in International Seminar Workshop on "Advances in Water Resources Management and Wastewater Treatment Technologies" 22-25 July 1996, on the occasion of 6th Anniversary Suranaree University of Technology, 1996.

TARLOCK A.D. Putting rivers back in the landscape: The revival of watershed management in the United States. *Hastings West-Northeest Journal of Environmental Low and Policy*, 2000, vol.6 (2-3), p. 167-195.

TOMPKINS E.L., ADGER W.N. Does Adaptive Management of Natural Resources Enhance Resilience to Climate Change? *Ecology and Society*, vol.9 (2). Available online at: http://www.ecologyandsociety.org/vol9/iss2/art10.

TRÉBUIL, G. Companion modelling for Resilient and adaptive social agro-ecological systems in Asia. Proceedings of the fourth National Agricultural Systems Conference "Agriculture for Community and Environment Ready to Handle Climate Change", Chiang Mai University, 2008, p. 90-104.

TRÉBUIL G., BOUSQUET F., EKASING B., BARON C., LE PAGE C. A multi-agent model linked to a GIS to explore the relationship between crop diversification and the risk of land degradation in northern Thailand highlands. In: *Companion Modeling and Multi-Agent Systems for Integrated Natural Resource Management in Asia*. B. Hardy, F. BOUSQUET, G. TRÉBUIL (Eds), Los Banos, Philippines : International Rice Research Institute (IRRI), 2005, p. 167-190.

TRÉBUIL G., EKASING B., BOUSQUET F., THONG-NGAM C. Multi-Agent Systems Companion Modeling for Integrated Watershed Management: A Northern Thailand Experience. In: *Landscapes of Diversity: Indigenous Knowledge, Sustainable Livelihoods and Resource Governance in Montane Mainland Southeast Asia*, X. JIANCHU, S. MIKESILL (Eds), 2003, p. 349-358.

VERBURG P., KOK K., PONTIUS R.G., VELDKAMP A. Modelling of land use and land cover changes. In: *Land Use and Land Cover Change: Local Processes, Global Impacts*, E. LAMBIN, H. GEIST (Eds). New York : Springer ,2006, p.117–135.

WAKEEL A., RAO K.S., MAIKHURI R.K., SAXENA K.G. Forest management and land use/cover changes in a typical micro watershed in the mid elevation zone of Central Himalaya, India. *Forest Ecology and Management*, 2005, vol.213 (1-3), p. 229-242.

WORLD BANK. *Africa Household Survey Data bank*, 2005a. Available online at: http://www4.worldbank.org/afr/poverty/databank/default.cfm

WORLD BANK. *Living Standards Measurement Study (LSMS) Database*, 2005b. Available online at: http://www.worldbank.org/lsms/

ZHANG Y., BARTEN P.K. Watershed Forest Management Information System (WFMIS). *Environmental Modelling & Software*, 2009, vol.24 (4), p. 569-575

APPENDICES

Appendix 1

1.1 Simulation data analysis on the "Business as usual"

1.1.1 Dependent Variable = TotalCash; Test of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1.769E13	47	3.763E11	17.625	.000	.657
Intercept	4.779E13	1	4.779E13	2238.443	.000	.838
Soc	5.186E8	1	5.186E8	.024	.876	.000
Lob	1.748E8	1	1.748E8	.008	.928	.000
San	**1.644E13**	**2**	**8.221E12**	**385.016**	**.000**	**.641**
Mon	5.248E10	1	5.248E10	2.458	.118	.006
VN	6.576E10	1	6.576E10	3.080	.080	.007
Soc * Lob	9.804E9	1	9.804E9	.459	.498	.001
Soc * San	5.669E10	2	2.835E10	1.328	.266	.006
Soc * Mon	2.414E7	1	2.414E7	.001	.973	.000
Soc * VN	6.300E9	1	6.300E9	.295	.587	.001
Lob * San	2.337E10	2	1.168E10	.547	.579	.003
Lob * Mon	3.852E10	1	3.852E10	1.804	.180	.004
Lob * VN	**9.147E10**	**1**	**9.147E10**	**4.284**	**.039**	**.010**
San * Mon	**1.640E11**	**2**	**8.202E10**	**3.841**	**.022**	**.017**
San * VN	**1.630E11**	**2**	**8.152E10**	**3.818**	**.023**	**.017**
Mon * VN	**8.457E10**	**1**	**8.457E10**	**3.961**	**.047**	**.009**
Soc * Lob * San	1.979E10	2	9.894E9	.463	.629	.002
Soc * Lob * Mon	4.587E9	1	4.587E9	.215	.643	.000
Soc * Lob * VN	8.160E10	1	8.160E10	3.822	.051	.009
Soc * San * Mon	1.257E11	2	6.286E10	2.944	.054	.013
Soc * San * VN	2.063E10	2	1.031E10	.483	.617	.002
Soc * Mon * VN	2.880E10	1	2.880E10	1.349	.246	.003
Lob * San * Mon	1.248E10	2	6.241E9	.292	.747	.001
Lob * San * VN	3.577E10	2	1.788E10	.838	.433	.004
Lob * Mon * VN	2.632E9	1	2.632E9	.123	.726	.000
San * Mon * VN	3.199E10	2	1.600E10	.749	.473	.003
Soc * Lob * San * Mon	4.226E9	2	2.113E9	.099	.906	.000
Soc * Lob * San * VN	4.723E10	2	2.362E10	1.106	.332	.005
Soc * Lob * Mon * VN	2.194E10	1	2.194E10	1.028	.311	.002
Soc * San * Mon * VN	1.764E10	2	8.820E9	.413	.662	.002
Lob * San * Mon * VN	1.045E10	2	5.227E9	.245	.783	.001
Soc * Lob * San * Mon * VN	2.323E10	2	1.162E10	.544	.581	.003
Error	9.224E12	432	2.135E10			
Total	7.471E13	480				
Corrected Total	2.691E13	479				

a. R Squared = .657 (Adjusted R Squared = .620)

1.1.2 Dependent Variable = TotalCash; Estimation Marginal Means

Soc	Lob	San	Mon	VN	Mean	Std. Error	95% Confidence Interval	
							Lower Bound	Upper Bound
1	1	1	1	1	104153.120	46207.817	13333.018	194973.222
				2	56294.370	46207.817	-34525.732	147114.472
			2	1	86985.310	46207.817	-3834.792	177805.412
				2	82224.360	46207.817	-8595.742	173044.462
		2	1	1	323299.540	46207.817	232479.438	414119.642
				2	445785.790	46207.817	354965.688	536605.892
			2	1	359962.585	46207.817	269142.483	450782.687
				2	353830.545	46207.817	263010.443	444650.647
		3	1	1	467549.760	46207.817	376729.658	558369.862
				2	521687.965	46207.817	430867.863	612508.067
			2	1	499516.625	46207.817	408696.523	590336.727
				2	519824.570	46207.817	429004.468	610644.672
	2	1	1	1	87101.475	46207.817	-3718.627	177921.577
				2	**-36386.350**	46207.817	-127206.452	54433.752
			2	1	157303.260	46207.817	66483.158	248123.362
				2	41719.530	46207.817	-49100.572	132539.632
		2	1	1	390854.425	46207.817	300034.323	481674.527
				2	331688.995	46207.817	240868.893	422509.097
			2	1	372870.900	46207.817	282050.798	463691.002
				2	309668.770	46207.817	218848.668	400488.872
		3	1	1	508829.290	46207.817	418009.188	599649.392
				2	445104.250	46207.817	354284.148	535924.352
			2	1	599632.220	46207.817	508812.118	690452.322
				2	518746.470	46207.817	427926.368	609566.572
2	1	1	1	1	80974.590	46207.817	-9845.512	171794.692
				2	6366.050	46207.817	-84454.052	97186.152
			2	1	157080.525	46207.817	66260.423	247900.627
				2	92744.425	46207.817	1924.323	183564.527
		2	1	1	348926.765	46207.817	258106.663	439746.867
				2	296739.015	46207.817	205918.913	387559.117
			2	1	339317.385	46207.817	248497.283	430137.487
				2	288327.610	46207.817	197507.508	379147.712
		3	1	1	477598.095	46207.817	386777.993	568418.197
				2	**632002.250**	46207.817	541182.148	722822.352
			2	1	508797.360	46207.817	417977.258	599617.462
				2	508722.070	46207.817	417901.968	599542.172
	2	1	1	1	22631.395	46207.817	-68188.707	113451.497
				2	-15543.620	46207.817	-106363.722	75276.482
			2	1	198352.635	46207.817	107532.533	289172.737
				2	66322.640	46207.817	-24497.462	157142.742
		2	1	1	298152.455	46207.817	207332.353	388972.557
				2	406285.450	46207.817	315465.348	497105.552

		2	1	366812.010	46207.817	275991.908	457632.112
			2	340905.645	46207.817	250085.543	431725.747
	3	1	1	532237.010	46207.817	441416.908	623057.112
			2	589922.030	46207.817	499101.928	680742.132
		2	1	565174.540	46207.817	474354.438	655994.642
			2	489292.750	46207.817	398472.648	580112.852

1.1.3 Dependent Variable = Gini; Test of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.522[a]	47	.011	9.821	.000	.517
Intercept	73.461	1	73.461	64973.651	.000	.993
Soc	.001	1	.001	.529	.467	.001
Lob	.002	1	.002	1.374	.242	.003
San	**.432**	**2**	**.216**	**191.049**	**.000**	**.469**
Mon	.003	1	.003	3.057	.081	.007
VN	.002	1	.002	1.841	.176	.004
Soc * Lob	.001	1	.001	1.075	.300	.002
Soc * San	.002	2	.001	1.070	.344	.005
Soc * Mon	.003	1	.003	2.305	.130	.005
Soc * VN	7.636E-6	1	7.636E-6	.007	.935	.000
Lob * San	**.025**	**2**	**.013**	**11.171**	**.000**	**.049**
Lob * Mon	.001	1	.001	.445	.505	.001
Lob * VN	.001	1	.001	.830	.363	.002
San * Mon	**.009**	**2**	**.004**	**3.879**	**.021**	**.018**
San * VN	.003	2	.001	1.140	.321	.005
Mon * VN	.000	1	.000	.131	.717	.000
Soc * Lob * San	**.008**	**2**	**.004**	**3.342**	**.036**	**.015**
Soc * Lob * Mon	.001	1	.001	1.031	.310	.002
Soc * Lob * VN	.003	1	.003	2.560	.110	.006
Soc * San * Mon	.004	2	.002	1.675	.188	.008
Soc * San * VN	.000	2	.000	.123	.884	.001
Soc * Mon * VN	.001	1	.001	.981	.322	.002
Lob * San * Mon	.001	2	.000	.306	.737	.001
Lob * San * VN	.005	2	.002	2.202	.112	.010
Lob * Mon * VN	.001	1	.001	.548	.460	.001
San * Mon * VN	.000	2	.000	.164	.849	.001
Soc * Lob * San * Mon	6.084E-5	2	3.042E-5	.027	.973	.000
Soc * Lob * San * VN	.000	2	.000	.161	.851	.001
Soc * Lob * Mon * VN	.002	1	.002	1.838	.176	.004
Soc * San * Mon * VN	.004	2	.002	1.615	.200	.007
Lob * San * Mon * VN	.000	2	9.988E-5	.088	.915	.000
Soc * Lob * San * Mon * VN	**.008**	**2**	**.004**	**3.502**	**.031**	**.016**
Error	.488	432	.001			
Total	74.471	480				
Corrected Total	1.010	479				

a. R Squared = .517 (Adjusted R Squared = .464)

1.1.4 Dependent Variable = Gini; Estimation Marginal Means

							95% Confidence Interval	
Soc	Lob	San	Mon	VN	Mean	Std. Error	Lower Bound	Upper Bound
1	1	1	1	1	.409	.011	.388	.430
				2	.423	.011	.402	.444
			2	1	.393	.011	.372	.414
				2	.429	.011	.408	.450
		2	1	1	.400	.011	.379	.421
				2	.407	.011	.386	.428
			2	1	.409	.011	.388	.430
				2	.411	.011	.391	.432
		3	1	1	.340	.011	.319	.361
				2	.363	.011	.342	.383
			2	1	.367	.011	.346	.388
				2	.359	.011	.338	.379
	2	1	1	1	**.445**	.011	.425	.466
				2	.433	.011	.412	.454
			2	1	.415	.011	.394	.436
				2	.416	.011	.395	.437
		2	1	1	.409	.011	.388	.430
				2	.395	.011	.374	.416
			2	1	.402	.011	.381	.422
				2	.408	.011	.387	.429
		3	1	1	.351	.011	.331	.372
				2	.336	.011	.316	.357
			2	1	.340	.011	.319	.361
				2	.354	.011	.333	.375
2	1	1	1	1	.400	.011	.379	.421
				2	.441	.011	.420	.462
			2	1	.408	.011	.387	.429
				2	.406	.011	.386	.427
		2	1	1	.427	.011	.406	.448
				2	.423	.011	.402	.444
			2	1	.401	.011	.381	.422
				2	.402	.011	.381	.423
		3	1	1	.367	.011	.346	.388
				2	**.335**	.011	.314	.356
			2	1	.352	.011	.331	.372
				2	.358	.011	.337	.379
	2	1	1	1	.438	.011	.417	.459
				2	.443	.011	.422	.464
			2	1	.423	.011	.402	.444
				2	.426	.011	.405	.447
		2	1	1	.386	.011	.365	.407
				2	.394	.011	.373	.415

		2	1	.372	.011	.351	.393
			2	.372	.011	.352	.393
	3	1	1	**.335**	.011	.314	.356
			2	.351	.011	.330	.372
		2	1	.348	.011	.327	.369
			2	.351	.011	.330	.372

1.1.5 Dependent Variable = cropFailedPlots; Test of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	137426.392[a]	47	2923.966	12.362	.000	.574
Intercept	1.135E8	1	1.135E8	479767.581	.000	.999
Soc	57.408	1	57.408	.243	.623	.001
Lob	145.200	1	145.200	.614	.434	.001
San	**129844.254**	**2**	**64922.127**	**274.473**	**.000**	**.560**
Mon	50.700	1	50.700	.214	.644	.000
VN	**1.200**	**1**	**1.200**	**.005**	**.943**	**.000**
Soc * Lob	86.700	1	86.700	.367	.545	.001
Soc * San	64.179	2	32.090	.136	.873	.001
Soc * Mon	**6.533**	**1**	**6.533**	**.028**	**.868**	**.000**
Soc * VN	38.533	1	38.533	.163	.687	.000
Lob * San	**4.662**	**2**	**2.331**	**.010**	**.990**	**.000**
Lob * Mon	**11.408**	**1**	**11.408**	**.048**	**.826**	**.000**
Lob * VN	357.075	1	357.075	1.510	.220	.003
San * Mon	**18.262**	**2**	**9.131**	**.039**	**.962**	**.000**
San * VN	41.413	2	20.706	.088	.916	.000
Mon * VN	42.008	1	42.008	.178	.674	.000
Soc * Lob * San	201.837	2	100.919	.427	.653	.002
Soc * Lob * Mon	**7.008**	**1**	**7.008**	**.030**	**.863**	**.000**
Soc * Lob * VN	492.075	1	492.075	2.080	.150	.005
Soc * San * Mon	502.604	2	251.302	1.062	.347	.005
Soc * San * VN	1625.804	2	812.902	3.437	.033	.016
Soc * Mon * VN	795.675	1	795.675	3.364	.067	.008
Lob * San * Mon	343.904	2	171.952	.727	.484	.003
Lob * San * VN	243.338	2	121.669	.514	.598	.002
Lob * Mon * VN	367.500	1	367.500	1.554	.213	.004
San * Mon * VN	244.054	2	122.027	.516	.597	.002
Soc * Lob * San * Mon	167.529	2	83.765	.354	.702	.002
Soc * Lob * San * VN	693.712	2	346.856	1.466	.232	.007
Soc * Lob * Mon * VN	28.033	1	28.033	.119	.731	.000
Soc * San * Mon * VN	631.962	2	315.981	1.336	.264	.006
Lob * San * Mon * VN	64.512	2	32.256	.136	.873	.001
Soc * Lob * San * Mon * VN	247.304	2	123.652	.523	.593	.002
Error	102182.400	432	236.533			
Total	1.137E8	480				
Corrected Total	239608.792	479				

a. R Squared = .574 (Adjusted R Squared = .527)

1.1.6 Dependent Variable = cropFailedPlots; Estimation Marginal Means

Soc	Lob	San	Mon	VN	Mean	Std. Error	95% Confidence Interval	
							Lower Bound	Upper Bound
1	1	1	1	1	502.900	4.863	493.341	512.459
				2	509.100	4.863	499.541	518.659
			2	1	507.700	4.863	498.141	517.259
				2	506.500	4.863	496.941	516.059
		2	1	1	488.100	4.863	478.541	497.659
				2	474.400	4.863	464.841	483.959
			2	1	486.300	4.863	476.741	495.859
				2	480.200	4.863	470.641	489.759
		3	1	1	471.300	4.863	461.741	480.859
				2	468.800	4.863	459.241	478.359
			2	1	469.000	4.863	459.441	478.559
				2	467.800	4.863	458.241	477.359
	2	1	1	1	503.000	4.863	493.441	512.559
				2	512.000	4.863	502.441	521.559
			2	1	506.600	4.863	497.041	516.159
				2	510.900	4.863	501.341	520.459
		2	1	1	478.300	4.863	468.741	487.859
				2	481.200	4.863	471.641	490.759
			2	1	483.200	4.863	473.641	492.759
				2	482.300	4.863	472.741	491.859
		3	1	1	462.500	4.863	452.941	472.059
				2	476.500	4.863	466.941	486.059
			2	1	467.700	4.863	458.141	477.259
				2	464.900	4.863	455.341	474.459
2	1	1	1	1	**516.000**	4.863	506.441	525.559
				2	505.800	4.863	496.241	515.359
			2	1	513.600	4.863	504.041	523.159
				2	508.200	4.863	498.641	517.759
		2	1	1	482.700	4.863	473.141	492.259
				2	486.500	4.863	476.941	496.059
			2	1	476.300	4.863	466.741	485.859
				2	485.800	4.863	476.241	495.359
		3	1	1	468.700	4.863	459.141	478.259
				2	461.300	4.863	451.741	470.859
			2	1	468.500	4.863	458.941	478.059
				2	477.200	4.863	467.641	486.759
	2	1	1	1	504.100	4.863	494.541	513.659
				2	507.900	4.863	498.341	517.459
			2	1	508.500	4.863	498.941	518.059
				2	508.400	4.863	498.841	517.959
		2	1	1	480.000	4.863	470.441	489.559

			2	482.300	4.863	472.741	491.859
		2	1	479.400	4.863	469.841	488.959
			2	482.700	4.863	473.141	492.259
	3	1	1	476.200	4.863	466.641	485.759
			2	**462.100**	4.863	452.541	471.659
		2	1	467.700	4.863	458.141	477.259
			2	467.900	4.863	458.341	477.459

1.1.7 Dependent Variable = newPlotCreated; Test of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	207330.925[a]	47	4411.296	338.968	.000	.974
Intercept	592629.075	1	592629.075	45538.200	.000	.991
Soc	32.033	1	32.033	2.461	.117	.006
Lob	25.208	1	25.208	1.937	.165	.004
San	**206005.888**	**2**	**103002.944**	**7914.847**	**.000**	**.973**
Mon	**192.533**	**1**	**192.533**	**14.794**	**.000**	**.033**
VN	9.633	1	9.633	.740	.390	.002
Soc * Lob	16.133	1	16.133	1.240	.266	.003
Soc * San	42.704	2	21.352	1.641	.195	.008
Soc * Mon	12.675	1	12.675	.974	.324	.002
Soc * VN	16.875	1	16.875	1.297	.255	.003
Lob * San	**166.754**	**2**	**83.377**	**6.407**	**.002**	**.029**
Lob * Mon	2.700	1	2.700	.207	.649	.000
Lob * VN	8.533	1	8.533	.656	.419	.002
San * Mon	20.204	2	10.102	.776	.461	.004
San * VN	**363.329**	**2**	**181.665**	**13.959**	**.000**	**.061**
Mon * VN	20.008	1	20.008	1.537	.216	.004
Soc * Lob * San	**120.254**	**2**	**60.127**	**4.620**	**.010**	**.021**
Soc * Lob * Mon	.408	1	.408	.031	.859	.000
Soc * Lob * VN	.408	1	.408	.031	.859	.000
Soc * San * Mon	28.438	2	14.219	1.093	.336	.005
Soc * San * VN	63.763	2	31.881	2.450	.088	.011
Soc * Mon * VN	16.133	1	16.133	1.240	.266	.003
Lob * San * Mon	19.888	2	9.944	.764	.466	.004
Lob * San * VN	14.679	2	7.340	.564	.569	.003
Lob * Mon * VN	29.008	1	29.008	2.229	.136	.005
San * Mon * VN	51.279	2	25.640	1.970	.141	.009
Soc * Lob * San * Mon	11.204	2	5.602	.430	.650	.002
Soc * Lob * San * VN	6.429	2	3.215	.247	.781	.001
Soc * Lob * Mon * VN	7.500	1	7.500	.576	.448	.001
Soc * San * Mon * VN	2.929	2	1.465	.113	.894	.001
Lob * San * Mon * VN	17.379	2	8.690	.668	.513	.003
Soc * Lob * San * Mon * VN	6.012	2	3.006	.231	.794	.001
Error	5622.000	432	13.014			
Total	805582.000	480				
Corrected Total	212952.925	479				

a. R Squared = .974 (Adjusted R Squared = .971)

1.1.8 Dependent Variable = newPlotCreated; Estimations of Marginal Means

Soc	Lob	San	Mon	VN	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	1	1	1	60.700	1.141	58.458	62.942
				2	62.200	1.141	59.958	64.442
			2	1	60.800	1.141	58.558	63.042
				2	62.700	1.141	60.458	64.942
		2	1	1	34.900	1.141	32.658	37.142
				2	35.800	1.141	33.558	38.042
			2	1	34.000	1.141	31.758	36.242
				2	32.200	1.141	29.958	34.442
		3	1	1	10.600	1.141	8.358	12.842
				2	11.000	1.141	8.758	13.242
			2	1	10.400	1.141	8.158	12.642
				2	8.900	1.141	6.658	11.142
	2	1	1	1	62.100	1.141	59.858	64.342
				2	61.700	1.141	59.458	63.942
			2	1	60.900	1.141	58.658	63.142
				2	63.400	1.141	61.158	65.642
		2	1	1	35.100	1.141	32.858	37.342
				2	32.800	1.141	30.558	35.042
			2	1	33.000	1.141	30.758	35.242
				2	32.500	1.141	30.258	34.742
		3	1	1	12.200	1.141	9.958	14.442
				2	11.300	1.141	9.058	13.542
			2	1	10.600	1.141	8.358	12.842
				2	9.700	1.141	7.458	11.942
2	1	1	1	1	59.000	1.141	56.758	61.242
				2	60.900	1.141	58.658	63.142
			2	1	54.100	1.141	51.858	56.342
				2	60.400	1.141	58.158	62.642
		2	1	1	34.900	1.141	32.658	37.142
				2	35.300	1.141	33.058	37.542
			2	1	32.900	1.141	30.658	35.142
				2	33.200	1.141	30.958	35.442
		3	1	1	11.700	1.141	9.458	13.942
				2	10.400	1.141	8.158	12.642
			2	1	11.600	1.141	9.358	13.842
				2	9.200	1.141	6.958	11.442
	2	1	1	1	61.300	1.141	59.058	63.542
				2	64.200	1.141	61.958	66.442
			2	1	59.300	1.141	57.058	61.542
				2	**64.600**	1.141	62.358	66.842
		2	1	1	36.000	1.141	33.758	38.242
				2	32.700	1.141	30.458	34.942

		2	1	32.900	1.141	30.658	35.142
			2	32.900	1.141	30.658	35.142
	3	1	1	11.500	1.141	9.258	13.742
			2	10.200	1.141	7.958	12.442
		2	1	9.400	1.141	7.158	11.642
			2	**8.500**	1.141	6.258	10.742

1.1.9 Dependent Variable = newPlotFound; Test of Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	6.858E6	47	145913.155	54.363	.000	.855
Intercept	2.500E7	1	2.500E7	9313.372	.000	.956
Soc	556.852	1	556.852	.207	.649	.000
Lob	9022.002	1	9022.002	3.361	.067	.008
San	**5808782.600**	**2**	**2904391.300**	**1082.096**	**.000**	**.834**
Mon	**542640.252**	**1**	**542640.252**	**202.173**	**.000**	**.319**
VN	**189170.502**	**1**	**189170.502**	**70.480**	**.000**	**.140**
Soc * Lob	6969.252	1	6969.252	2.597	.108	.006
Soc * San	**19602.617**	**2**	**9801.308**	**3.652**	**.027**	**.017**
Soc * Mon	47.502	1	47.502	.018	.894	.000
Soc * VN	268.502	1	268.502	.100	.752	.000
Lob * San	434.817	2	217.408	.081	.922	.000
Lob * Mon	390.602	1	390.602	.146	.703	.000
Lob * VN	3712.969	1	3712.969	1.383	.240	.003
San * Mon	**186532.717**	**2**	**93266.358**	**34.748**	**.000**	**.139**
San * VN	**24673.017**	**2**	**12336.508**	**4.596**	**.011**	**.021**
Mon * VN	19.602	1	19.602	.007	.932	.000
Soc * Lob * San	3250.217	2	1625.108	.605	.546	.003
Soc * Lob * Mon	19.602	1	19.602	.007	.932	.000
Soc * Lob * VN	4338.019	1	4338.019	1.616	.204	.004
Soc * San * Mon	2233.617	2	1116.808	.416	.660	.002
Soc * San * VN	15283.517	2	7641.758	2.847	.059	.013
Soc * Mon * VN	99.919	1	99.919	.037	.847	.000
Lob * San * Mon	218.867	2	109.433	.041	.960	.000
Lob * San * VN	702.450	2	351.225	.131	.877	.001
Lob * Mon * VN	1006.302	1	1006.302	.375	.541	.001
San * Mon * VN	**22502.317**	**2**	**11251.158**	**4.192**	**.016**	**.019**
Soc * Lob * San * Mon	1127.017	2	563.508	.210	.811	.001
Soc * Lob * San * VN	5400.200	2	2700.100	1.006	.367	.005
Soc * Lob * Mon * VN	362.269	1	362.269	.135	.714	.000
Soc * San * Mon * VN	3333.800	2	1666.900	.621	.538	.003
Lob * San * Mon * VN	5030.317	2	2515.158	.937	.393	.004
Soc * Lob * San * Mon * VN	**186.050**	**2**	**93.025**	**.035**	**.966**	**.000**
Error	1159506.300	432	2684.042			
Total	3.301E7	480				
Corrected Total	8017424.581	479				

a. R Squared = .855 (Adjusted R Squared = .840)

1.1.10 Dependent Variable = newPlotFound; Estimations Marginal Means

Soc	Lob	San	Mon	VN	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	1	1	1	332.200	16.383	300.000	364.400
				2	259.800	16.383	227.600	292.000
			2	1	424.600	16.383	392.400	456.800
				2	403.200	16.383	371.000	435.400
		2	1	1	217.000	16.383	184.800	249.200
				2	167.100	16.383	134.900	199.300
			2	1	262.100	16.383	229.900	294.300
				2	234.500	16.383	202.300	266.700
		3	1	1	**51.700**	16.383	19.500	83.900
				2	89.100	16.383	56.900	121.300
			2	1	106.200	16.383	74.000	138.400
				2	80.300	16.383	48.100	112.500
	2	1	1	1	336.800	16.383	304.600	369.000
				2	260.900	16.383	228.700	293.100
			2	1	**451.800**	16.383	419.600	484.000
				2	407.500	16.383	375.300	439.700
		2	1	1	233.100	16.383	200.900	265.300
				2	179.100	16.383	146.900	211.300
			2	1	290.400	16.383	258.200	322.600
				2	232.900	16.383	200.700	265.100
		3	1	1	104.500	16.383	72.300	136.700
				2	87.000	16.383	54.800	119.200
			2	1	144.400	16.383	112.200	176.600
				2	94.900	16.383	62.700	127.100
2	1	1	1	1	332.000	16.383	299.800	364.200
				2	256.900	16.383	224.700	289.100
			2	1	442.600	16.383	410.400	474.800
				2	386.700	16.383	354.500	418.900
		2	1	1	240.300	16.383	208.100	272.500
				2	211.400	16.383	179.200	243.600
			2	1	261.800	16.383	229.600	294.000
				2	271.100	16.383	238.900	303.300
		3	1	1	83.600	16.383	51.400	115.800
				2	52.700	16.383	20.500	84.900
			2	1	137.200	16.383	105.000	169.400
				2	68.800	16.383	36.600	101.000
	2	1	1	1	334.200	16.383	302.000	366.400
				2	268.900	16.383	236.700	301.100
			2	1	451.600	16.383	419.400	483.800
				2	385.200	16.383	353.000	417.400
		2	1	1	231.300	16.383	199.100	263.500
				2	209.100	16.383	176.900	241.300

		2	1	291.300	16.383	259.100	323.500
			2	256.400	16.383	224.200	288.600
	3	1	1	74.100	16.383	41.900	106.300
			2	57.200	16.383	25.000	89.400
		2	1	118.600	16.383	86.400	150.800
			2	79.800	16.383	47.600	112.000

1.1.11 Dependent Variable = newPlotClaimed; Test of Between-SubjectsEeffects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	185492.131[a]	47	3946.641	227.779	.000	.961
Intercept	497103.769	1	497103.769	28690.175	.000	.985
Soc	7.252	1	7.252	.419	.518	.001
Lob	17.252	1	17.252	.996	.319	.002
San	**184033.613**	**2**	**92016.806**	**5310.719**	**.000**	**.961**
Mon	15.052	1	15.052	.869	.352	.002
VN	43.802	1	43.802	2.528	.113	.006
Soc * Lob	15.052	1	15.052	.869	.352	.002
Soc * San	66.354	2	33.177	1.915	.149	.009
Soc * Mon	5.419	1	5.419	.313	.576	.001
Soc * VN	4.602	1	4.602	.266	.607	.001
Lob * San	**189.504**	**2**	**94.752**	**5.469**	**.005**	**.025**
Lob * Mon	.252	1	.252	.015	.904	.000
Lob * VN	8.269	1	8.269	.477	.490	.001
San * Mon	61.879	2	30.940	1.786	.169	.008
San * VN	**522.629**	**2**	**261.315**	**15.082**	**.000**	**.065**
Mon * VN	22.969	1	22.969	1.326	.250	.003
Soc * Lob * San	**119.279**	**2**	**59.640**	**3.442**	**.033**	**.016**
Soc * Lob * Mon	.002	1	.002	.000	.991	.000
Soc * Lob * VN	.352	1	.352	.020	.887	.000
Soc * San * Mon	25.138	2	12.569	.725	.485	.003
Soc * San * VN	**113.854**	**2**	**56.927**	**3.286**	**.038**	**.015**
Soc * Mon * VN	17.252	1	17.252	.996	.319	.002
Lob * San * Mon	30.404	2	15.202	.877	.417	.004
Lob * San * VN	8.887	2	4.444	.256	.774	.001
Lob * Mon * VN	51.352	1	51.352	2.964	.086	.007
San * Mon * VN	24.462	2	12.231	.706	.494	.003
Soc * Lob * San * Mon	8.129	2	4.065	.235	.791	.001
Soc * Lob * San * VN	28.579	2	14.290	.825	.439	.004
Soc * Lob * Mon * VN	21.252	1	21.252	1.227	.269	.003
Soc * San * Mon * VN	1.504	2	.752	.043	.958	.000
Lob * San * Mon * VN	17.954	2	8.977	.518	.596	.002
Soc * Lob * San * Mon * VN	9.829	2	4.915	.284	.753	.001
Error	7485.100	432	17.327			
Total	690081.000	480				
Corrected Total	192977.231	479				

a. R Squared = .961 (Adjusted R Squared = .957)

1.1.12 Dependent Variable = newPlotClaimed; Estimation Marginal Means

							95% Confidence Interval	
Soc	Lob	San	Mon	VN	Mean	Std. Error	Lower Bound	Upper Bound
1	1	1	1	1	56.000	1.316	53.413	58.587
				2	58.300	1.316	55.713	60.887
			2	1	56.900	1.316	54.313	59.487
				2	57.900	1.316	55.313	60.487
		2	1	1	31.400	1.316	28.813	33.987
				2	32.200	1.316	29.613	34.787
			2	1	30.500	1.316	27.913	33.087
				2	29.500	1.316	26.913	32.087
		3	1	1	7.300	1.316	4.713	9.887
				2	9.100	1.316	6.513	11.687
			2	1	9.800	1.316	7.213	12.387
				2	8.600	1.316	6.013	11.187
	2	1	1	1	57.100	1.316	54.513	59.687
				2	58.200	1.316	55.613	60.787
			2	1	55.800	1.316	53.213	58.387
				2	**59.400**	1.316	56.813	61.987
		2	1	1	30.800	1.316	28.213	33.387
				2	28.500	1.316	25.913	31.087
			2	1	29.300	1.316	26.713	31.887
				2	30.000	1.316	27.413	32.587
		3	1	1	10.600	1.316	8.013	13.187
				2	9.000	1.316	6.413	11.587
			2	1	9.700	1.316	7.113	12.287
				2	9.400	1.316	6.813	11.987
2	1	1	1	1	53.500	1.316	50.913	56.087
				2	57.600	1.316	55.013	60.187
			2	1	49.800	1.316	47.213	52.387
				2	57.200	1.316	54.613	59.787
		2	1	1	32.200	1.316	29.613	34.787
				2	32.000	1.316	29.413	34.587
			2	1	30.700	1.316	28.113	33.287
				2	30.800	1.316	28.213	33.387
		3	1	1	**9.500**	1.316	6.913	12.087
				2	7.200	1.316	4.613	9.787
			2	1	11.100	1.316	8.513	13.687
				2	8.700	1.316	6.113	11.287
	2	1	1	1	56.800	1.316	54.213	59.387
				2	60.600	1.316	58.013	63.187
			2	1	55.100	1.316	52.513	57.687
				2	60.200	1.316	57.613	62.787
		2	1	1	33.100	1.316	30.513	35.687
				2	28.800	1.316	26.213	31.387

		2	1	29.900	1.316	27.313	32.487
			2	30.400	1.316	27.813	32.987
	3	1	1	9.000	1.316	6.413	11.587
			2	7.800	1.316	5.213	10.387
		2	1	9.200	1.316	6.613	11.787
			2	8.200	1.316	5.613	10.787

1.2 Simulation data analysis on the “Limiting pipe size”

1.2.1 Dependent Variable = TotalCash; Test of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	3.278E14	47	6.974E12	108.887	.000	.922
Intercept	6.471E13	1	6.471E13	1010.416	.000	.701
Soc	1.396E10	1	1.396E10	.218	.641	.001
Lob	**2.987E12**	**1**	**2.987E12**	**46.637**	**.000**	**.097**
San	**3.038E14**	**2**	**1.519E14**	**2372.028**	**.000**	**.917**
Mon	8.132E10	1	8.132E10	1.270	.260	.003
VN	**1.834E12**	**1**	**1.834E12**	**28.635**	**.000**	**.062**
Soc * Lob	1912712.750	1	1912712.750	.000	.996	.000
Soc * San	**5.066E11**	**2**	**2.533E11**	**3.955**	**.020**	**.018**
Soc * Mon	**4.275E11**	**1**	**4.275E11**	**6.675**	**.010**	**.015**
Soc * VN	5.620E10	1	5.620E10	.877	.349	.002
Lob * San	**7.155E12**	**2**	**3.578E12**	**55.859**	**.000**	**.205**
Lob * Mon	**6.226E11**	**1**	**6.226E11**	**9.722**	**.002**	**.022**
Lob * VN	**7.940E11**	**1**	**7.940E11**	**12.398**	**.000**	**.028**
San * Mon	**4.183E11**	**2**	**2.091E11**	**3.265**	**.039**	**.015**
San * VN	**2.409E12**	**2**	**1.205E12**	**18.810**	**.000**	**.080**
Mon * VN	**5.925E11**	**1**	**5.925E11**	**9.250**	**.002**	**.021**
Soc * Lob * San	1.268E11	2	6.341E10	.990	.372	.005
Soc * Lob * Mon	3.382E9	1	3.382E9	.053	.818	.000
Soc * Lob * VN	5.400E10	1	5.400E10	.843	.359	.002
Soc * San * Mon	1.592E11	2	7.960E10	1.243	.290	.006
Soc * San * VN	2.439E11	2	1.219E11	1.904	.150	.009
Soc * Mon * VN	1.670E11	1	1.670E11	2.607	.107	.006
Lob * San * Mon	**4.089E11**	**2**	**2.044E11**	**3.192**	**.042**	**.015**
Lob * San * VN	**4.379E12**	**2**	**2.190E12**	**34.188**	**.000**	**.137**
Lob * Mon * VN	9.292E10	1	9.292E10	1.451	.229	.003
San * Mon * VN	7.396E10	2	3.698E10	.577	.562	.003
Soc * Lob * San * Mon	6.411E9	2	3.206E9	.050	.951	.000
Soc * Lob * San * VN	9.063E10	2	4.531E10	.708	.493	.003
Soc * Lob * Mon * VN	7.439E9	1	7.439E9	.116	.733	.000
Soc * San * Mon * VN	3.100E10	2	1.550E10	.242	.785	.001
Lob * San * Mon * VN	8.864E10	2	4.432E10	.692	.501	.003
Soc * Lob * San * Mon * VN	9.866E10	2	4.933E10	.770	.464	.004
Error	2.767E13	432	6.405E10			
Total	4.202E14	480				
Corrected Total	3.554E14	479				

a. R Squared = .922 (Adjusted R Squared = .914)

1.2.2 Dependent Variable = TotalCash; Estimation Marginal Means

							95% Confidence Interval	
Soc	Lob	San	Mon	VN	Mean	Std. Error	Lower Bound	Upper Bound
1	1	1	1	1	-732537.920	80029.275	-889833.100	-575242.740
				2	**-1463659.300**	80029.275	-1620954.480	-1306364.120
			2	1	-623709.200	80029.275	-781004.380	-466414.020
				2	-1396174.260	80029.275	-1553469.440	-1238879.080
		2	1	1	910247.040	80029.275	752951.860	1067542.220
				2	888663.440	80029.275	731368.260	1045958.620
			2	1	864982.020	80029.275	707686.840	1022277.200
				2	636750.150	80029.275	479454.970	794045.330
		3	1	1	1222257.730	80029.275	1064962.550	1379552.910
				2	**1270517.385**	80029.275	1113222.205	1427812.565
			2	1	864730.410	80029.275	707435.230	1022025.590
				2	1082934.550	80029.275	925639.370	1240229.730
	2	1	1	1	-604097.670	80029.275	-761392.850	-446802.490
				2	-552004.000	80029.275	-709299.180	-394708.820
			2	1	-431550.560	80029.275	-588845.740	-274255.380
				2	-546275.970	80029.275	-703571.150	-388980.790
		2	1	1	849317.225	80029.275	692022.045	1006612.405
				2	908947.920	80029.275	751652.740	1066243.100
			2	1	934300.760	80029.275	777005.580	1091595.940
				2	922187.675	80029.275	764892.495	1079482.855
		3	1	1	1028120.240	80029.275	870825.060	1185415.420
				2	947017.950	80029.275	789722.770	1104313.130
			2	1	1060396.810	80029.275	903101.630	1217691.990
				2	900362.875	80029.275	743067.695	1057658.055
2	1	1	1	1	-731376.850	80029.275	-888672.030	-574081.670
				2	-1295465.700	80029.275	-1452760.880	-1138170.520
			2	1	-584495.020	80029.275	-741790.200	-427199.840
				2	-1172468.020	80029.275	-1329763.200	-1015172.840
		2	1	1	715530.345	80029.275	558235.165	872825.525
				2	878038.915	80029.275	720743.735	1035334.095
			2	1	807438.820	80029.275	650143.640	964734.000
				2	763243.210	80029.275	605948.030	920538.390
		3	1	1	971242.510	80029.275	813947.330	1128537.690
				2	1102077.740	80029.275	944782.560	1259372.920
			2	1	1005037.900	80029.275	847742.720	1162333.080
				2	935265.490	80029.275	777970.310	1092560.670
	2	1	1	1	-663933.790	80029.275	-821228.970	-506638.610
				2	-409556.230	80029.275	-566851.410	-252261.050
			2	1	-359582.450	80029.275	-516877.630	-202287.270
				2	-485377.440	80029.275	-642672.620	-328082.260
		2	1	1	702336.650	80029.275	545041.470	859631.830
				2	834042.400	80029.275	676747.220	991337.580

		2	1	977417.410	80029.275	820122.230	1134712.590
			2	817816.780	80029.275	660521.600	975111.960
	3	1	1	903012.025	80029.275	745716.845	1060307.205
			2	821176.290	80029.275	663881.110	978471.470
		2	1	1210717.325	80029.275	1053422.145	1368012.505
			2	940751.600	80029.275	783456.420	1098046.780

1.2.3 Dependent Variable = Gini; Test Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1.862[a]	47	.040	32.109	.000	.777
Intercept	72.956	1	72.956	59115.464	.000	.993
Soc	.002	1	.002	1.246	.265	.003
Lob	**.081**	**1**	**.081**	**65.818**	**.000**	**.132**
San	**1.567**	**2**	**.783**	**634.711**	**.000**	**.746**
Mon	.004	1	.004	3.084	.080	.007
VN	**.009**	**1**	**.009**	**7.015**	**.008**	**.016**
Soc * Lob	**.006**	**1**	**.006**	**4.648**	**.032**	**.011**
Soc * San	.007	2	.004	2.916	.055	.013
Soc * Mon	.002	1	.002	1.549	.214	.004
Soc * VN	**.018**	**1**	**.018**	**14.947**	**.000**	**.033**
Lob * San	**.008**	**2**	**.004**	**3.088**	**.047**	**.014**
Lob * Mon	.002	1	.002	1.321	.251	.003
Lob * VN	.004	1	.004	3.487	.063	.008
San * Mon	.001	2	.000	.335	.716	.002
San * VN	.004	2	.002	1.443	.237	.007
Mon * VN	.001	1	.001	.982	.322	.002
Soc * Lob * San	.005	2	.003	2.058	.129	.009
Soc * Lob * Mon	.002	1	.002	1.604	.206	.004
Soc * Lob * VN	.002	1	.002	1.585	.209	.004
Soc * San * Mon	**.013**	**2**	**.006**	**5.104**	**.006**	**.023**
Soc * San * VN	.004	2	.002	1.770	.172	.008
Soc * Mon * VN	4.663E-5	1	4.663E-5	.038	.846	.000
Lob * San * Mon	.002	2	.001	.936	.393	.004
Lob * San * VN	**.018**	**2**	**.009**	**7.189**	**.001**	**.032**
Lob * Mon * VN	**.012**	**1**	**.012**	**9.513**	**.002**	**.022**
San * Mon * VN	**.015**	**2**	**.007**	**5.901**	**.003**	**.027**
Soc * Lob * San * Mon	**.030**	**2**	**.015**	**12.107**	**.000**	**.053**
Soc * Lob * San * VN	**.009**	**2**	**.004**	**3.550**	**.030**	**.016**
Soc * Lob * Mon * VN	.003	1	.003	2.312	.129	.005
Soc * San * Mon * VN	.007	2	.003	2.703	.068	.012
Lob * San * Mon * VN	.003	2	.001	1.144	.319	.005
Soc * Lob * San * Mon * VN	**.025**	**2**	**.012**	**10.045**	**.000**	**.044**
Error	.533	432	.001			
Total	75.352	480				
Corrected Total	2.396	479				

a. R Squared = .777 (Adjusted R Squared = .753)

1.2.4 Dependent Variable = Gini; Estimation Marginal Means

Soc	Lob	San	Mon	VN	Mean	Std. Error	95% Confidence Interval	
							Lower Bound	Upper Bound
1	1	1	1	1	.486	.011	.464	.507
				2	.472	.011	.450	.493
			2	1	.475	.011	.453	.497
				2	.469	.011	.447	.491
		2	1	1	.313	.011	.291	.335
				2	.380	.011	.358	.402
			2	1	.398	.011	.376	.420
				2	.377	.011	.355	.399
		3	1	1	.336	.011	.314	.358
				2	.381	.011	.359	.403
			2	1	.336	.011	.314	.358
				2	.349	.011	.327	.371
	2	1	1	1	.477	.011	.455	.499
				2	.470	.011	.448	.492
			2	1	.458	.011	.436	.480
				2	.466	.011	.444	.488
		2	1	1	.365	.011	.343	.387
				2	.354	.011	.332	.375
			2	1	.321	.011	.300	.343
				2	.357	.011	.335	.379
		3	1	1	.334	.011	.312	.355
				2	.300	.011	.279	.322
			2	1	.335	.011	.313	.357
				2	.306	.011	.284	.328
2	1	1	1	1	**.517**	.011	.496	.539
				2	.466	.011	.445	.488
			2	1	.498	.011	.476	.520
				2	.461	.011	.439	.483
		2	1	1	.414	.011	.392	.435
				2	.389	.011	.368	.411
			2	1	.351	.011	.330	.373
				2	.368	.011	.346	.390
		3	1	1	.325	.011	.304	.347
				2	.367	.011	.345	.388
			2	1	.400	.011	.378	.422
				2	.340	.011	.318	.362
	2	1	1	1	.462	.011	.440	.484
				2	.429	.011	.407	.451
			2	1	.442	.011	.420	.464
				2	.454	.011	.432	.476
		2	1	1	.383	.011	.361	.405
				2	.353	.011	.331	.375

	2	1	.385	.011	.363	.407
		2	.329	.011	.308	.351
3	1	1	.332	.011	.310	.354
		2	.320	.011	.298	.341
	2	1	.315	.011	.294	.337
		2	**.298**	.011	.276	.319

1.2.5 Dependent Variable = cropFailedPlots; Test of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1.575E6	47	33501.677	7.605	.000	.453
Intercept	3.517E7	1	3.517E7	7984.473	.000	.949
Soc	2920.533	1	2920.533	.663	.416	.002
Lob	12000.000	1	12000.000	2.724	.100	.006
San	**1052916.350**	**2**	**526458.175**	**119.507**	**.000**	**.356**
Mon	264.033	1	264.033	.060	.807	.000
VN	**66270.000**	**1**	**66270.000**	**15.043**	**.000**	**.034**
Soc * Lob	218.700	1	218.700	.050	.824	.000
Soc * San	16919.617	2	8459.808	1.920	.148	.009
Soc * Mon	20436.300	1	20436.300	4.639	.032	.011
Soc * VN	8704.033	1	8704.033	1.976	.161	.005
Lob * San	50516.250	2	25258.125	5.734	.003	.026
Lob * Mon	18451.200	1	18451.200	4.188	.041	.010
Lob * VN	5936.133	1	5936.133	1.348	.246	.003
San * Mon	52498.817	2	26249.408	5.959	.003	.027
San * VN	35192.150	2	17596.075	3.994	.019	.018
Mon * VN	21816.033	1	21816.033	4.952	.027	.011
Soc * Lob * San	13797.450	2	6898.725	1.566	.210	.007
Soc * Lob * Mon	537.633	1	537.633	.122	.727	.000
Soc * Lob * VN	17184.133	1	17184.133	3.901	.049	.009
Soc * San * Mon	11180.600	2	5590.300	1.269	.282	.006
Soc * San * VN	1429.517	2	714.758	.162	.850	.001
Soc * Mon * VN	13824.533	1	13824.533	3.138	.077	.007
Lob * San * Mon	33693.450	2	16846.725	3.824	.023	.017
Lob * San * VN	59987.817	2	29993.908	6.809	.001	.031
Lob * Mon * VN	4272.133	1	4272.133	.970	.325	.002
San * Mon * VN	10976.117	2	5488.058	1.246	.289	.006
Soc * Lob * San * Mon	2866.067	2	1433.033	.325	.722	.002
Soc * Lob * San * VN	12577.717	2	6288.858	1.428	.241	.007
Soc * Lob * Mon * VN	10010.133	1	10010.133	2.272	.132	.005
Soc * San * Mon * VN	4687.267	2	2343.633	.532	.588	.002
Lob * San * Mon * VN	5564.217	2	2782.108	.632	.532	.003
Soc * Lob * San * Mon * VN	6929.867	2	3464.933	.787	.456	.004
Error	1903072.000	432	4405.259			
Total	3.865E7	480				
Corrected Total	3477650.800	479				

a. R Squared = .453 (Adjusted R Squared = .393)

1.2.6 Dependent Variable = cropFailedPlots; Etmation Marginal Means

Soc	Lob	San	Mon	VN	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	1	1	1	381.400	20.989	340.147	422.653
				2	367.400	20.989	326.147	408.653
			2	1	348.500	20.989	307.247	389.753
				2	362.400	20.989	321.147	403.653
		2	1	1	226.100	20.989	184.847	267.353
				2	232.100	20.989	190.847	273.353
			2	1	214.500	20.989	173.247	255.753
				2	271.000	20.989	229.747	312.253
		3	1	1	**173.900**	20.989	132.647	215.153
				2	176.200	20.989	134.947	217.453
			2	1	278.900	20.989	237.647	320.153
				2	238.300	20.989	197.047	279.553
	2	1	1	1	379.000	20.989	337.747	420.253
				2	288.500	20.989	247.247	329.753
			2	1	333.500	20.989	292.247	374.753
				2	280.300	20.989	239.047	321.553
		2	1	1	238.700	20.989	197.447	279.953
				2	203.800	20.989	162.547	245.053
			2	1	250.300	20.989	209.047	291.553
				2	201.800	20.989	160.547	243.053
		3	1	1	228.800	20.989	187.547	270.053
				2	253.500	20.989	212.247	294.753
			2	1	255.100	20.989	213.847	296.353
				2	253.600	20.989	212.347	294.853
2	1	1	1	1	379.300	20.989	338.047	420.553
				2	357.900	20.989	316.647	399.153
			2	1	338.000	20.989	296.747	379.253
				2	301.500	20.989	260.247	342.753
		2	1	1	271.000	20.989	229.747	312.253
				2	209.700	20.989	168.447	250.953
			2	1	258.500	20.989	217.247	299.753
				2	234.500	20.989	193.247	275.753
		3	1	1	261.700	20.989	220.447	302.953
				2	206.200	20.989	164.947	247.453
			2	1	275.400	20.989	234.147	316.653
				2	252.400	20.989	211.147	293.653
	2	1	1	1	**397.500**	20.989	356.247	438.753
				2	259.900	20.989	218.647	301.153
			2	1	326.600	20.989	285.347	367.853
				2	288.100	20.989	246.847	329.353
		2	1	1	273.300	20.989	232.047	314.553
				2	213.200	20.989	171.947	254.453

		2	1	210.400	20.989	169.147	251.653
			2	249.900	20.989	208.647	291.153
	3	1	1	268.500	20.989	227.247	309.753
			2	267.000	20.989	225.747	308.253
		2	1	209.900	20.989	168.647	251.153
			2	245.600	20.989	204.347	286.853

1.2.7 Dependent Variable = newPlotCreated; Test of between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	6.574E6	47	139872.133	1724.210	.000	.995
Intercept	6822769.852	1	6822769.852	84104.579	.000	.995
Soc	**394.219**	**1**	**394.219**	**4.860**	**.028**	**.011**
Lob	**18787.519**	**1**	**18787.519**	**231.595**	**.000**	**.349**
San	**6520176.579**	**2**	**3260088.290**	**40187.250**	**.000**	**.995**
Mon	**1852.602**	**1**	**1852.602**	**22.837**	**.000**	**.050**
VN	**3167.269**	**1**	**3167.269**	**39.043**	**.000**	**.083**
Soc * Lob	155.269	1	155.269	1.914	.167	.004
Soc * San	93.862	2	46.931	.579	.561	.003
Soc * Mon	262.552	1	262.552	3.236	.073	.007
Soc * VN	28.519	1	28.519	.352	.554	.001
Lob * San	4169.062	2	2084.531	25.696	.000	.106
Lob * Mon	1095.052	1	1095.052	13.499	.000	.030
Lob * VN	206.719	1	206.719	2.548	.111	.006
San * Mon	2137.579	2	1068.790	13.175	.000	.057
San * VN	14607.163	2	7303.581	90.032	.000	.294
Mon * VN	7.252	1	7.252	.089	.765	.000
Soc * Lob * San	648.613	2	324.306	3.998	.019	.018
Soc * Lob * Mon	253.752	1	253.752	3.128	.078	.007
Soc * Lob * VN	176.419	1	176.419	2.175	.141	.005
Soc * San * Mon	87.279	2	43.640	.538	.584	.002
Soc * San * VN	**3.462**	**2**	**1.731**	**.021**	**.979**	**.000**
Soc * Mon * VN	5.852	1	5.852	.072	.788	.000
Lob * San * Mon	629.479	2	314.740	3.880	.021	.018
Lob * San * VN	2525.513	2	1262.756	15.566	.000	.067
Lob * Mon * VN	**.252**	**1**	**.252**	**.003**	**.956**	**.000**
San * Mon * VN	262.529	2	131.265	1.618	.199	.007
Soc * Lob * San * Mon	527.579	2	263.790	3.252	.040	.015
Soc * Lob * San * VN	100.612	2	50.306	.620	.538	.003
Soc * Lob * Mon * VN	**651.002**	**1**	**651.002**	**8.025**	**.005**	**.018**
Soc * San * Mon * VN	428.079	2	214.040	2.638	.073	.012
Lob * San * Mon * VN	19.529	2	9.765	.120	.887	.001
Soc * Lob * San * Mon * VN	529.079	2	264.540	3.261	.039	.015
Error	35044.900	432	81.122			
Total	1.343E7	480				
Corrected Total	6609035.148	479				

a. R Squared = .995 (Adjusted R Squared = .994)

1.2.8 Dependent Variable = newPlotCreated; Estimateion Marginal Means

							95% Confidence Interval	
Soc	Lob	San	Mon	VN	Mean	Std. Error	Lower Bound	Upper Bound
1	1	1	1	1	274.600	2.848	269.002	280.198
				2	282.100	2.848	276.502	287.698
			2	1	265.000	2.848	259.402	270.598
				2	265.200	2.848	259.602	270.798
		2	1	1	56.300	2.848	50.702	61.898
				2	47.400	2.848	41.802	52.998
			2	1	64.200	2.848	58.602	69.798
				2	44.000	2.848	38.402	49.598
		3	1	1	12.600	2.848	7.002	18.198
				2	8.000	2.848	2.402	13.598
			2	1	10.500	2.848	4.902	16.098
				2	8.000	2.848	2.402	13.598
	2	1	1	1	283.700	2.848	278.102	289.298
				2	294.900	2.848	289.302	300.498
			2	1	279.000	2.848	273.402	284.598
				2	**297.000**	2.848	291.402	302.598
		2	1	1	85.000	2.848	79.402	90.598
				2	61.500	2.848	55.902	67.098
			2	1	78.500	2.848	72.902	84.098
				2	61.400	2.848	55.802	66.998
		3	1	1	17.600	2.848	12.002	23.198
				2	10.800	2.848	5.202	16.398
			2	1	20.700	2.848	15.102	26.298
				2	11.600	2.848	6.002	17.198
2	1	1	1	1	288.600	2.848	283.002	294.198
				2	287.300	2.848	281.702	292.898
			2	1	270.300	2.848	264.702	275.898
				2	268.000	2.848	262.402	273.598
		2	1	1	71.700	2.848	66.102	77.298
				2	46.500	2.848	40.902	52.098
			2	1	54.900	2.848	49.302	60.498
				2	44.100	2.848	38.502	49.698
		3	1	1	13.600	2.848	8.002	19.198
				2	8.600	2.848	3.002	14.198
			2	1	12.000	2.848	6.402	17.598
				2	**7.700**	2.848	2.102	13.298
	2	1	1	1	276.200	2.848	270.602	281.798
				2	303.100	2.848	297.502	308.698
			2	1	278.700	2.848	273.102	284.298
				2	289.100	2.848	283.502	294.698
		2	1	1	83.900	2.848	78.302	89.498
				2	63.800	2.848	58.202	69.398

		2	1	86.000	2.848	80.402	91.598
			2	66.600	2.848	61.002	72.198
	3	1	1	19.800	2.848	14.202	25.398
			2	10.900	2.848	5.302	16.498
		2	1	19.600	2.848	14.002	25.198
			2	12.100	2.848	6.502	17.698

1.2.9. Dependent Variable = newPlotFound; Test of Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1.699E7	47	361397.207	251.159	.000	.965
Intercept	1.997E7	1	1.997E7	13879.890	.000	.970
Soc	**29531.719**	**1**	**29531.719**	**20.524**	**.000**	**.045**
Lob	**678529.602**	**1**	**678529.602**	**471.556**	**.000**	**.522**
San	**1.301E7**	**2**	**6505856.269**	**4521.356**	**.000**	**.954**
Mon	**55706.752**	**1**	**55706.752**	**38.714**	**.000**	**.082**
VN	**1892164.102**	**1**	**1892164.102**	**1314.992**	**.000**	**.753**
Soc * Lob	1270.752	1	1270.752	.883	.348	.002
Soc * San	**16764.788**	**2**	**8382.394**	**5.825**	**.003**	**.026**
Soc * Mon	**67095.052**	**1**	**67095.052**	**46.629**	**.000**	**.097**
Soc * VN	4483.519	1	4483.519	3.116	.078	.007
Lob * San	**171169.204**	**2**	**85584.602**	**59.478**	**.000**	**.216**
Lob * Mon	**19089.019**	**1**	**19089.019**	**13.266**	**.000**	**.030**
Lob * VN	**9301.602**	**1**	**9301.602**	**6.464**	**.011**	**.015**
San * Mon	7980.929	2	3990.465	2.773	.064	.013
San * VN	**870334.404**	**2**	**435167.202**	**302.427**	**.000**	**.583**
Mon * VN	2137.852	1	2137.852	1.486	.224	.003
Soc * Lob * San	6014.504	2	3007.252	2.090	.125	.010
Soc * Lob * Mon	**20007.919**	**1**	**20007.919**	**13.905**	**.000**	**.031**
Soc * Lob * VN	717.852	1	717.852	.499	.480	.001
Soc * San * Mon	**32092.829**	**2**	**16046.415**	**11.152**	**.000**	**.049**
Soc * San * VN	2751.388	2	1375.694	.956	.385	.004
Soc * Mon * VN	**10575.019**	**1**	**10575.019**	**7.349**	**.007**	**.017**
Lob * San * Mon	3170.113	2	1585.056	1.102	.333	.005
Lob * San * VN	1787.504	2	893.752	.621	.538	.003
Lob * Mon * VN	665.052	1	665.052	.462	.497	.001
San * Mon * VN	4285.879	2	2142.940	1.489	.227	.007
Soc * Lob * San * Mon	**24557.262**	**2**	**12278.631**	**8.533**	**.000**	**.038**
Soc * Lob * San * VN	3913.704	2	1956.852	1.360	.258	.006
Soc * Lob * Mon * VN	3270.852	1	3270.852	2.273	.132	.005
Soc * San * Mon * VN	4702.512	2	2351.256	1.634	.196	.008
Lob * San * Mon * VN	2560.729	2	1280.365	.890	.411	.004
Soc * Lob * San * Mon * VN	**27323.779**	**2**	**13661.890**	**9.495**	**.000**	**.042**
Error	621612.100	432	1438.917			
Total	3.758E7	480				
Corrected Total	1.761E7	479				

a. R Squared = .965 (Adjusted R Squared = .961)

1.2.10 Dependent Variable = newPlotFound; Estimation Marginal Means

Soc	Lob	San	Mon	VN	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	1	1	1	535.800	11.995	512.223	559.377
				2	273.500	11.995	249.923	297.077
			2	1	472.900	11.995	449.323	496.477
				2	278.700	11.995	255.123	302.277
		2	1	1	142.800	11.995	119.223	166.377
				2	53.900	11.995	30.323	77.477
			2	1	191.200	11.995	167.623	214.777
				2	50.100	11.995	26.523	73.677
		3	1	1	26.000	11.995	2.423	49.577
				2	9.000	11.995	-14.577	32.577
			2	1	28.200	11.995	4.623	51.777
				2	9.100	11.995	-14.477	32.677
	2	1	1	1	**624.700**	11.995	601.123	648.277
				2	368.300	11.995	344.723	391.877
			2	1	611.600	11.995	588.023	635.177
				2	358.700	11.995	335.123	382.277
		2	1	1	300.700	11.995	277.123	324.277
				2	141.800	11.995	118.223	165.377
			2	1	264.700	11.995	241.123	288.277
				2	164.400	11.995	140.823	187.977
		3	1	1	57.800	11.995	34.223	81.377
				2	20.200	11.995	-3.377	43.777
			2	1	75.600	11.995	52.023	99.177
				2	24.100	11.995	.523	47.677
2	1	1	1	1	460.700	11.995	437.123	484.277
				2	231.600	11.995	208.023	255.177
			2	1	521.400	11.995	497.823	544.977
				2	272.800	11.995	249.223	296.377
		2	1	1	131.400	11.995	107.823	154.977
				2	48.800	11.995	25.223	72.377
			2	1	130.800	11.995	107.223	154.377
				2	50.000	11.995	26.423	73.577
		3	1	1	19.500	11.995	-4.077	43.077
				2	10.000	11.995	-13.577	33.577
			2	1	36.500	11.995	12.923	60.077
				2	**8.500**	11.995	-15.077	32.077
	2	1	1	1	510.900	11.995	487.323	534.477
				2	298.000	11.995	274.423	321.577
			2	1	610.400	11.995	586.823	633.977
				2	371.600	11.995	348.023	395.177
		2	1	1	188.500	11.995	164.923	212.077
				2	125.500	11.995	101.923	149.077

		2	1	341.500	11.995	317.923	365.077
			2	179.500	11.995	155.923	203.077
	3	1	1	47.800	11.995	24.223	71.377
			2	9.800	11.995	-13.777	33.377
		2	1	71.000	11.995	47.423	94.577
			2	30.800	11.995	7.223	54.377

1.2.11 Dependent Variable = newPlotClaimed; Test of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	6.337E6	47	134829.568	1540.270	.000	.994
Intercept	6510719.602	1	6510719.602	74377.332	.000	.994
Soc	**478.002**	**1**	**478.002**	**5.461**	**.020**	**.012**
Lob	**16626.302**	**1**	**16626.302**	**189.936**	**.000**	**.305**
San	**6283532.404**	**2**	**3141766.202**	**35890.992**	**.000**	**.994**
Mon	**1137.752**	**1**	**1137.752**	**12.997**	**.000**	**.029**
VN	**2095.852**	**1**	**2095.852**	**23.943**	**.000**	**.053**
Soc * Lob	50.052	1	50.052	.572	.450	.001
Soc * San	167.579	2	83.790	.957	.385	.004
Soc * Mon	262.552	1	262.552	2.999	.084	.007
Soc * VN	47.502	1	47.502	.543	.462	.001
Lob * San	**3206.804**	**2**	**1603.402**	**18.317**	**.000**	**.078**
Lob * Mon	**840.052**	**1**	**840.052**	**9.597**	**.002**	**.022**
Lob * VN	58.102	1	58.102	.664	.416	.002
San * Mon	**1996.829**	**2**	**998.415**	**11.406**	**.000**	**.050**
San * VN	**19008.529**	**2**	**9504.265**	**108.575**	**.000**	**.335**
Mon * VN	19.602	1	19.602	.224	.636	.001
Soc * Lob * San	**618.529**	**2**	**309.265**	**3.533**	**.030**	**.016**
Soc * Lob * Mon	**431.302**	**1**	**431.302**	**4.927**	**.027**	**.011**
Soc * Lob * VN	201.502	1	201.502	2.302	.130	.005
Soc * San * Mon	80.104	2	40.052	.458	.633	.002
Soc * San * VN	6.554	2	3.277	.037	.963	.000
Soc * Mon * VN	60.919	1	60.919	.696	.405	.002
Lob * San * Mon	**635.629**	**2**	**317.815**	**3.631**	**.027**	**.017**
Lob * San * VN	**2708.679**	**2**	**1354.340**	**15.472**	**.000**	**.067**
Lob * Mon * VN	9.919	1	9.919	.113	.737	.000
San * Mon * VN	324.154	2	162.077	1.852	.158	.008
Soc * Lob * San * Mon	448.854	2	224.427	2.564	.078	.012
Soc * Lob * San * VN	54.654	2	27.327	.312	.732	.001
Soc * Lob * Mon * VN	**994.752**	**1**	**994.752**	**11.364**	**.001**	**.026**
Soc * San * Mon * VN	226.213	2	113.106	1.292	.276	.006
Lob * San * Mon * VN	61.137	2	30.569	.349	.705	.002
Soc * Lob * San * Mon * VN	598.879	2	299.440	3.421	.034	.016
Error	37815.700	432	87.536			
Total	1.289E7	480				
Corrected Total	6374805.398	479				

a. R Squared = .994 (Adjusted R Squared = .993)

1.2.12 Dependent Variable = newPlotClaimed; Estimation Marginal Means

							95% Confidence Interval	
Soc	Lob	San	Mon	VN	Mean	Std. Error	Lower Bound	Upper Bound
1	1	1	1	1	264.900	2.959	259.085	270.715
				2	279.200	2.959	273.385	285.015
			2	1	260.800	2.959	254.985	266.615
				2	261.900	2.959	256.085	267.715
		2	1	1	53.000	2.959	47.185	58.815
				2	46.200	2.959	40.385	52.015
			2	1	63.800	2.959	57.985	69.615
				2	43.500	2.959	37.685	49.315
		3	1	1	11.400	2.959	5.585	17.215
				2	7.900	2.959	2.085	13.715
			2	1	10.500	2.959	4.685	16.315
				2	8.000	2.959	2.185	13.815
	2	1	1	1	275.600	2.959	269.785	281.415
				2	290.500	2.959	284.685	296.315
			2	1	270.500	2.959	264.685	276.315
				2	291.800	2.959	285.985	297.615
		2	1	1	83.000	2.959	77.185	88.815
				2	55.700	2.959	49.885	61.515
			2	1	75.700	2.959	69.885	81.515
				2	57.200	2.959	51.385	63.015
		3	1	1	17.000	2.959	11.185	22.815
				2	10.800	2.959	4.985	16.615
			2	1	20.700	2.959	14.885	26.515
				2	11.600	2.959	5.785	17.415
2	1	1	1	1	281.800	2.959	275.985	287.615
				2	283.200	2.959	277.385	289.015
			2	1	263.000	2.959	257.185	268.815
				2	264.600	2.959	258.785	270.415
		2	1	1	68.700	2.959	62.885	74.515
				2	44.300	2.959	38.485	50.115
			2	1	53.700	2.959	47.885	59.515
				2	43.900	2.959	38.085	49.715
		3	1	1	13.400	2.959	7.585	19.215
				2	7.300	2.959	1.485	13.115
			2	1	11.200	2.959	5.385	17.015
				2	**7.700**	2.959	1.885	13.515
	2	1	1	1	269.300	2.959	263.485	275.115
				2	**297.100**	2.959	291.285	302.915
			2	1	272.700	2.959	266.885	278.515
				2	285.900	2.959	280.085	291.715
		2	1	1	81.800	2.959	75.985	87.615
				2	60.300	2.959	54.485	66.115

		2	1	84.900	2.959	79.085	90.715
			2	63.400	2.959	57.585	69.215
	3	1	1	18.800	2.959	12.985	24.615
			2	10.900	2.959	5.085	16.715
		2	1	19.100	2.959	13.285	24.915
			2	12.100	2.959	6.285	17.915

1.2.13 Dependent Variable = pipeScore; Test Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	241918.592[a]	47	5147.204	3.989	.000	.303
Intercept	1.343E7	1	1.343E7	10412.132	.000	.960
Soc	1178.133	1	1178.133	.913	.340	.002
Lob	**10697.408**	**1**	**10697.408**	**8.291**	**.004**	**.019**
San	**75733.129**	**2**	**37866.565**	**29.348**	**.000**	**.120**
Mon	468.075	1	468.075	.363	.547	.001
VN	**10546.875**	**1**	**10546.875**	**8.174**	**.004**	**.019**
Soc * Lob	896.533	1	896.533	.695	.405	.002
Soc * San	2136.329	2	1068.165	.828	.438	.004
Soc * Mon	**8670.000**	**1**	**8670.000**	**6.720**	**.010**	**.015**
Soc * VN	3763.200	1	3763.200	2.917	.088	.007
Lob * San	**31140.204**	**2**	**15570.102**	**12.068**	**.000**	**.053**
Lob * Mon	**5454.008**	**1**	**5454.008**	**4.227**	**.040**	**.010**
Lob * VN	745.008	1	745.008	.577	.448	.001
San * Mon	**18827.113**	**2**	**9413.556**	**7.296**	**.001**	**.033**
San * VN	**7819.737**	**2**	**3909.869**	**3.030**	**.049**	**.014**
Mon * VN	7316.408	1	7316.408	5.671	.018	.013
Soc * Lob * San	2866.254	2	1433.127	1.111	.330	.005
Soc * Lob * Mon	136.533	1	136.533	.106	.745	.000
Soc * Lob * VN	**6870.533**	**1**	**6870.533**	**5.325**	**.021**	**.012**
Soc * San * Mon	2205.262	2	1102.631	.855	.426	.004
Soc * San * VN	1335.938	2	667.969	.518	.596	.002
Soc * Mon * VN	**9117.633**	**1**	**9117.633**	**7.067**	**.008**	**.016**
Lob * San * Mon	**9784.404**	**2**	**4892.202**	**3.792**	**.023**	**.017**
Lob * San * VN	**10912.379**	**2**	**5456.190**	**4.229**	**.015**	**.019**
Lob * Mon * VN	.675	1	.675	.001	.982	.000
San * Mon * VN	2965.954	2	1482.977	1.149	.318	.005
Soc * Lob * San * Mon	658.204	2	329.102	.255	.775	.001
Soc * Lob * San * VN	3382.129	2	1691.065	1.311	.271	.006
Soc * Lob * Mon * VN	1569.633	1	1569.633	1.217	.271	.003
Soc * San * Mon * VN	2284.304	2	1142.152	.885	.413	.004
Lob * San * Mon * VN	826.913	2	413.456	.320	.726	.001
Soc * Lob * San * Mon * VN	1609.679	2	804.840	.624	.536	.003
Error	557385.400	432	1290.244			
Total	1.423E7	480				
Corrected Total	799303.992	479				

a. R Squared = .303 (Adjusted R Squared = .227)

1.2.14 Dependent Variable = pipeScore; Estimation Marginal Means

Soc	Lob	San	Mon	VN	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	1	1	1	123.600	11.359	101.274	145.926
				2	130.800	11.359	108.474	153.126
			2	1	142.500	11.359	120.174	164.826
				2	129.700	11.359	107.374	152.026
		2	1	1	193.500	11.359	171.174	215.826
				2	179.900	11.359	157.574	202.226
			2	1	186.100	11.359	163.774	208.426
				2	155.900	11.359	133.574	178.226
		3	1	1	**212.100**	11.359	189.774	234.426
				2	208.000	11.359	185.674	230.326
			2	1	154.100	11.359	131.774	176.426
				2	169.900	11.359	147.574	192.226
	2	1	1	1	141.800	11.359	119.474	164.126
				2	176.700	11.359	154.374	199.026
			2	1	159.000	11.359	136.674	181.326
				2	182.400	11.359	160.074	204.726
		2	1	1	182.400	11.359	160.074	204.726
				2	188.700	11.359	166.374	211.026
			2	1	167.200	11.359	144.874	189.526
				2	192.200	11.359	169.874	214.526
		3	1	1	182.600	11.359	160.274	204.926
				2	169.100	11.359	146.774	191.426
			2	1	158.800	11.359	136.474	181.126
				2	165.700	11.359	143.374	188.026
2	1	1	1	1	**113.900**	11.359	91.574	136.226
				2	134.900	11.359	112.574	157.226
			2	1	142.200	11.359	119.874	164.526
				2	155.700	11.359	133.374	178.026
		2	1	1	149.500	11.359	127.174	171.826
				2	194.500	11.359	172.174	216.826
			2	1	170.800	11.359	148.474	193.126
				2	175.300	11.359	152.974	197.626
		3	1	1	164.700	11.359	142.374	187.026
				2	197.800	11.359	175.474	220.126
			2	1	156.600	11.359	134.274	178.926
				2	159.800	11.359	137.474	182.126
	2	1	1	1	129.300	11.359	106.974	151.626
				2	190.800	11.359	168.474	213.126
			2	1	162.600	11.359	140.274	184.926
				2	179.100	11.359	156.774	201.426
		2	1	1	158.700	11.359	136.374	181.026
				2	190.500	11.359	168.174	212.826

		2	1	195.700	11.359	173.374	218.026
			2	169.200	11.359	146.874	191.526
	3	1	1	164.200	11.359	141.874	186.526
			2	160.800	11.359	138.474	183.126
		2	1	190.700	11.359	168.374	213.026
			2	170.200	11.359	147.874	192.526