Part 2 Companion Modelling (ComMod) to understand the interaction between land & water use and labour migration

CHAPTER VI
COLLABORATIVE MODELLING APPROACHES FOR RENEWABLE RESOURCE MANAGEMENT

Collaborative or participatory approaches emerged as a response to lengthy and top-down planning processes in rural development projects and to the failure of the transfer-of-technology model which had been predominant from 1960 to the early 1980s (Neef, 2005). Such technological transfers are likely to fail in highly heterogeneous and marginal areas when top-down developments are implemented regardless of the involvement of concerned stakeholders (Ashby and Sperling, 1995). However, when stakeholders are involved, inviting them to participate is often not genuine: they are merely sought to increase the legitimacy of developments projects (Bishop and Davis, 2002).

Genuine implementation of participatory processes requires the use of interactive techniques. Organizing workshops based on collective model building, scenario development and exploration represents one of the most promising techniques to set up a communication platform generating multi-directional flows of information between stakeholders (Stringer, Dougill et al., 2006)

In this chapter, collaborative modelling refers to the process of designing and/or using models collectively, as distinguished by Renger, Kolfschoten et al (2008). Several similar terms are used to refer to the same general principle: group model building (Vennix, 1996), mediated modelling (Van den Belt, 2004), cooperative modelling (Cockerill, Passell et al., 2006), and participatory modelling (Hare, Letcher et al., 2003). This chapter begins with general considerations about models and the modelling process. The collaborative modelling approach is then introduced and to illustrate its diversity, a comparative analysis of six collaborative modelling case studies is subsequently presented in this chapter.

6.1. Diversity of Models, Sequentiality of the Modelling Process

6.1.1. Characteristics of Models

A model is a simplified representation of an actual system, a synthesis of what we know about the system with references to the problem at stake (Banks, 1998; Jorgensen and Bendoricchio, 2001). There is a huge diversity in the types of models and many criteria can be considered to propose a typology of models. The most commonly referred criteria are briefly reviewed below.

A physical model is a real manipulable artefact such as a scale model of an aeroplane used for aerodynamic testing in a wind tunnel (Jorgensen et al., 2001). In contrast, models without a physical existence are called "abstract" models. This category can itself be classified into three subcategories: conceptual, mathematical and computational models. Conceptual models are simple drawings: diagrams. Mathematical models make use of equations to depict the reference system. Computational models are designed by using programming languages or specific software.

Time is another dimension to characterize models (Alan and Banks, 1998). In static models, the changes in variables defining the system are not dependent on time, which is the case for dynamic models. Dynamic models can be further classified into discrete-change and continuous-change models. The spatial representation is also used to classify types of model. Spatially-explicit models, frequently used to tackle RRM issues, provide a representation of space. However, many disciplines use the term 'spatially explicit', but in different ways. Four tests are proposed by Parker (2001) to determine whether a model is 'really' spatially explicit.

6.1.2. Objectives for the Implementation of a Model

The objectives for the design and use of a model are often specific to each case study. Therefore, like model characteristics, they are also very diverse. Yet publications presenting models do not always provide clear indications about the objective related to the models. This is an issue, as the objective drives the design of a model and has to serve as the main justification for modelling choices. Four main objectives often cited are: (i) to understand the system or problem in a virtual laboratory (as explanatory devices); (ii) to determine critical elements, components, and issues and to estimate performance measures (as an analysis tool); (iii) to represent system operation and a means of communicating science and the results of science (as a communication vehicle), and (iv) to predict the consequences of proposed scenarios. (Carley, 1999; Epstein, 2008; Jorgensen et al., 2001; Wainwright and Mulligan, 2004).

Nonetheless, to investigate the complexity of human-environment interactions at work in socio-ecosystems, abstract simulation models are usually implemented. The modelling objectives are then to gain better understanding about the system under study, to promote communication, and to support decision-making.

6.1.3. The Sequentiality of the Modelling process

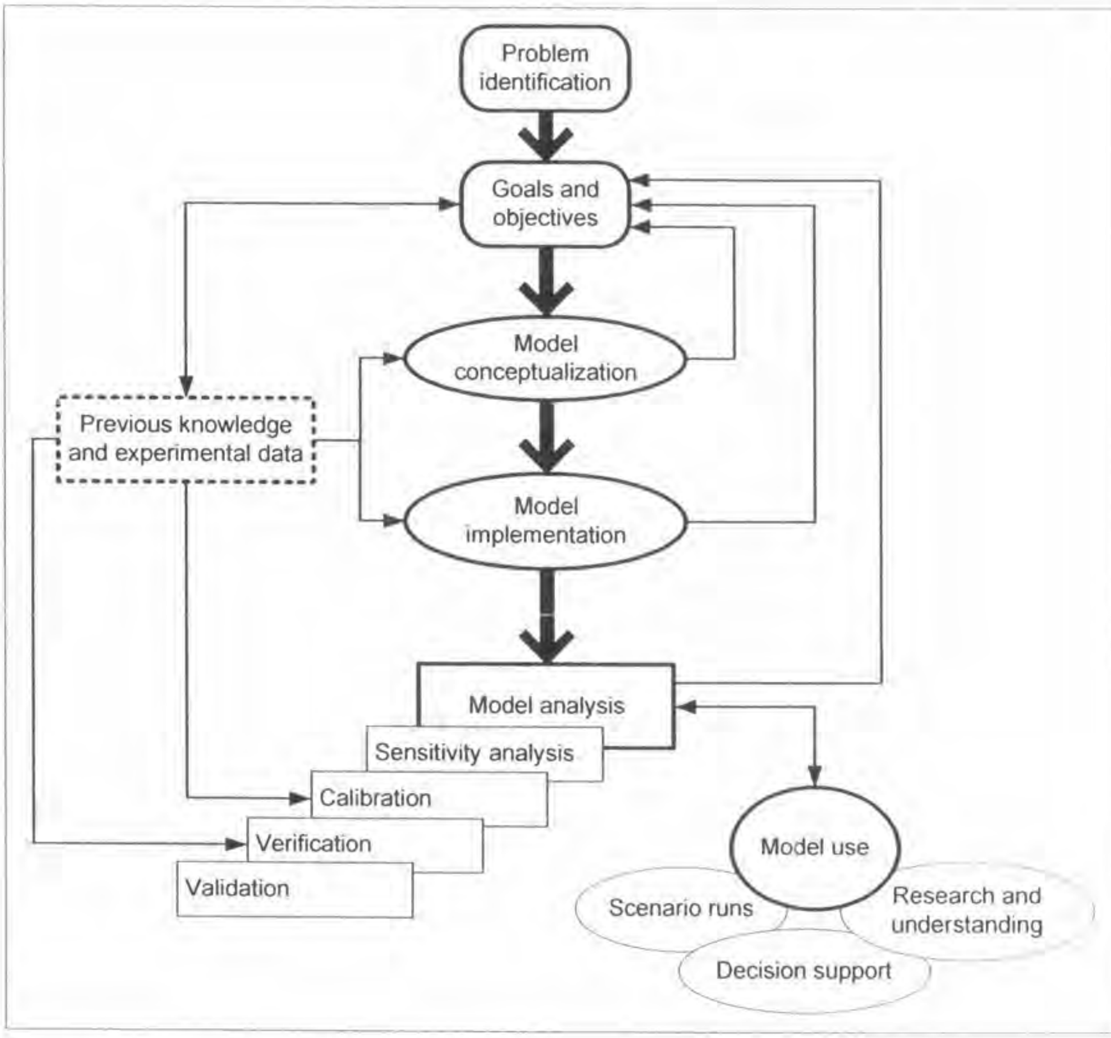
Figure 6.1 shows the key stages of the modelling process as proposed by Voinov and Bouman (2004). Different modelling stages have been proposed by several authors (Banks, 1998; Jakeman, Letcher et al., 2006; Komklom and Puckdeewattanakul, 2005). Unlike model characteristics and objectives, descriptions of the modelling process share strong similarities. The various terms used to identify the modelling stages can be grouped into *two* main phases: model design and model use. It is also commonly stressed that the modelling process is unlikely to flow linearly but rather comes and goes iteratively between stages.

6.2. Collaborative Modelling Approaches

There are some stages in the design and/or use of models that involve several persons. The term 'collaborative', or 'participatory', modelling refers to such group model building situations where model designers and/or users are actively involved (Eden et al., 1996).

6.2.1. Collaborative Modelling Background

Collaborative modelling approaches stem from system dynamics, and usually refer to integrated ecological modelling. The idea is that a system's point of view is helpful to 'lift' observers to the system's level and to create a holistic view. Several methods have been developed to support such an idea, ranging from problem structuring and the system's conceptualization (e.g. cognitive mapping) to the construction of computer models simulating the behaviours of stakeholders interacting within a complex socio-ecosystem.



Source: adapted from Voinov and Bouman, 2004.

Figure 6.1 An example of the sequentiality of the modelling process.

In ecology, hard and soft systems are often referred to (Röling and Wagmaker, 1998). Hard systems are treated as if the systems really exist. The systems' boundaries and goals are assumed to be given. Analysis and problem solving focus on goal seeking and the best technical means to reach a goal. The crucial assumption is that system goals are not given but contested, and that system boundaries are negotiated. The soft systems methodology emphasizes a group of actors who are faced with a shared problem to engage in a collective learning process. A combination of both systems methodologies (soft and hard sciences) and participatory action research can theoretically facilitate the integration of various disciplines and different types of knowledge. Such a combination is consistent with the definition of soft systems methodology, and is referred to as collaborative modelling (Purnomo, Yasmi et al., 2003).

6.2.1.1. Diversity in Collaborative Group Composition

The types of disciplines and number of collaborators involved in the modelling process can determine the base of knowledge integrated into the model. Frequently, modelling has primarily been used by natural scientists as a means of capturing and predicting aspects of complex systems, usually within monodisciplinary boundaries (e.g. crop models, hydrological models). These kinds of "expert models" are inadequate to understand non-linear, complex and dynamic systems such as in the field of economics where several components of human-environment interactions are involved (Prell, Huback et al., 2007). Thus, economists have adopted modelling in different ways to integrate the product of several disciplines into an economic model. However, these multidisciplinary models are usually implemented and used within the scientific arena. This kind of modelling approach is based on optimization and 'factual knowledge' that is insufficient for multi-level and multi-actor involvement, in particular rural development (Prell et al., 2007). The involvement of lay stakeholders throughout the model development process is proposed to avoid relying exclusively on knowledge derived from policy-makers and scientists (Purnomo et al., 2003). Therefore, the engagement of non-scientific stakeholders is needed if investigation of a RRM issue is targeted.

Participation of non-scientists in the production and use of scientific knowledge was introduced by social scientists who believe that science is socially constructed and should not be restricted solely to the scientific arena. Research on participation in science pay more attention to gaining support for decisions and enriching assessments with lay-knowledge and opinions (van Asselt, Mellors et al., 2001). Involving non-scientists in the research process is increasingly important in the analysis of complex issues. Such issues concern a tangled web of related problems (multi-problem), lie across or at the intersection of many disciplines (multi-disciplinary), and the underlying processes interact on various spatial and temporal scales (multi-scale) involving different stakeholders (multi-actors) (van Asselt and Rijkens-Klomp, 2002). However, indigenous knowledge alone is not sufficient

(Ostrom, Schroeder et al., 1993). Thus, integrating knowledge from different sources through collaborative processes can be a promising way for all relevant stakeholders to gain better understanding of the current situation of the system under study.

6.2.1.2. Collaborative Model: the Integration between Local and Scientific Knowledge

Knowledge integration that combines local and scientific knowledge is a challenging issue in scientific research (Neef, 2005). Local knowledge is primarily concerned with sustaining people's livelihoods in harmony with nature. It is closed, non-systematic and bound to subjectivity, common sense or superstition. In contrast, science is open, systematic and objective, rigorous and analytical.

Because local knowledge is deeply embedded in the social, cultural and moral context, it is important to better understand this informative base of a society. Such information is needed to facilitate communication and decision-making resulting in the creation of an environment. This is conducive to collaborative processes that bridge the divide between local and scientific knowledge. Thus, in a collaborative modelling process, stakeholders play a proactive, central role in the design team, working together with modellers that can result in more practical designs and acceptable development (Schuler and Namioka, 1993). Through the collaborative and communicative platform, the knowledge-sharing activity is enhanced leading to shared representation developed among heterogeneous stakeholders (Ashby, 2003; Narayan, 1996; Pahl-Wostl, 2006; Selener, 1997). The collaborative modelling process also supports capacity building (Fitzpatrick and Sinclair, 2003), helps to resolve conflicts and build consensus (Walkerden, 2006), and creates networking opportunity (Roux, Rogers et al., 2006).

6.2.2. Collaborative Modelling Phases

Collaborative modelling process is a continuous spiral of collective decision cycles generally consisting of five main phases: problem identification and structuring, model conceptualization, model implementation and validation, scenario exploration, and monitoring and evaluation of the model used (Daniell and Ferrand, 2006). The degree of stakeholder involvement, in the collaborative modelling process, is varied. They can engage exclusively during the model design phase or simply be the end users of the model; the model can also be co-designed with, and used by the stakeholders.

6.2.2.1. Model Design Phase

Problem identification and formulation

This phase underlies the theory to elicit the individual perceptions to determine the nature of the situation where the problem is found, what elements are important to the problem, and how participants believe these elements to be related to one another over a variety of scales (Daniell et al., 2006). The aim is to create a shared understanding about the identity and extent of the problematic issues. It also allows a group of people to become acquainted with each other along with the development of problem structuring (Andersen and Richardson, 1997; Winz and Brierley, 2007).

In this phase, the involvement of a broad representation of stakeholder groups affected by the problem is essential. While the problem is collectively structured, the objectives to be achieved or situations to be avoided are also often determined. Once objectives are elucidated, potential processes, strategies or plans can be designed. The preliminary findings at this phase are useful for formalizing an initial conceptual model.

Model conceptualization

The model conceptualization is an analytical task that abstracts the system into a model described by elements of the system, their characteristics, and their interactions (Musselman, 1998). The representation of the users' perceptions and conceptions in relation to the system where the users reside is reflected in the conceptual model (David, 2002). Maintaining stakeholder involvement and using information provided by participants during this stage can create trust in the modeller and the model-building process (Ford and Sterman, 1998). A conceptual model can be presented in various kinds of visualization ranging from simple and organized writing or diagrammatic flowcharts to computer-based applications. It can be used as a tool to facilitate effective and efficient communication between participants regarding a model's structure, components and operations (van Asselt et al., 2001). Once the initial conceptual model is formalized to sufficiently represent the system under study, it is developed to become an artefact aiming to further analyze the effect of potential actions may occur under defined problematic situations.

Model implementation and validation

This modelling stage captures the conceptual model using the constructs of a simulation language or system. Translation of the conceptual model into a programmed model constitutes the process of programming to build an executable simulation model. Additional information beyond the initial thinking is usually obtained during this model co-constructing activity. It includes re-examining the hypotheses used in the model, and refining the work of model development through verification and validation procedures. Three significant steps in the modelling procedure need to be defined in this section. They are calibration, verification and validation (Jorgensen et al., 2001). Calibration is an attempt to find the best accordance between computed and observed data by variation of some selected parameters (Hansen and Heckman, 1996). If not, the model is adjusted by modifying the values of certain parameters. Verification is a determinant of whether the computer implementation of the conceptual model is correct. It is a test of the internal logic of the model, and a subjective assessment of the behaviour of the model.

Once a model is operational after verification testing, the model needs to be checked for its validity and whether or not it is a good model of what it is supposed to represent. Validation is a determinant of whether the conceptual model can be substituted for the real system for the purpose of experimentation (Balci, 1998). An objective is to test how well the model outputs fit the data. Since the model is co-constructed with field collaborators, the model validation is often carried out in parallel with model implementation. Involving stakeholders can ensure that the content of the model is believable, its outcomes plausible, and that it sufficiently represents the problem being examined (Daniell et al., 2006). Successful projects depend on valid models, sound statistical analyses, and cogent reasoning (Musselman, 1998). It is important that model validity is accepted by stakeholders. Once the programmed model is completed and valid, it is ready to be used for running virtual experiments. The process of experimenting with the simulations is to evaluate system behaviour, to analyze model sensitivity, to determine functional relations, and to train people involved in the modelling process (Balci, 1998).

6.2.2.2. Model Use Phase

This phase focuses on producing scenarios and management options by using the model. The scenarios to be analyzed should be collectively identified and explored by stakeholders. Possible solutions for desirable solutions are collectively analyzed through the outputs of simulations. However, no model can replace individual thought. Thus, the purpose of using models at this phase of the collaborative modelling process is to support the collective decision-making process, not to supplant it (Daniell et al., 2006). Neubert (2000) proposed two efforts that should be taken into account once carrying out scenario exploration. First, the discovery-oriented effort is to produce new knowledge about organizational or institutional innovation processes. Second, the literacy-oriented effort is to build individuals' and communities' capacities to handle their problems themselves. In reality, both discovery- and literacy-oriented efforts are often interlinked.

After exploring interesting scenarios, the synthesis of preferred actions drawn from desirable scenarios can be collectively assessed for the purposes of making a final decision and a collective agreement to implement an action plan. As stakeholders actively involved in the model design phase, their acceptance of and commitment to a model's outcomes is high. Other positive outcomes can be increased independence, self-awareness, and empowerment of stakeholders to address local problems independently.

6.2.2.3. Monitoring and Evaluation

The monitoring and evaluation activity plays an important role in assessing the success of the collaborative modelling process. This activity is proposed to ensure that tasks are carried out according to the action plan. Any problem encountered can be treated on an ongoing basis through adaptive management. As an intervention measure, if the evaluation is carried out by the participants, they will be required to think about what is occurring in the process which can then potentially change their behaviour and have further impacts on the process and its outcomes (Daniell et al., 2006). As an aid to the overall utility, outcomes and perceptions of the process can be used to determine how such a process can be improved.

6.2.3. Methods and Modelling Tools

Although the participants collaboratively working with modellers is important, methods and modelling tools used are also a determining factor in successful collaborative modelling. Group discussion is often a primary method in collaborative modelling. Other participatory methods (individual interviews, focus groups, etc.) can be used in the collaborative modelling process as well. Tools can be simple drawings or complicated computer simulations, or combination of both.

Methods and tools used in collaborative modelling aim to examine the system under study qualitatively and quantitatively. For qualitative methods, the cognitive mapping using software packages such as Decision Explorer and DANA, and problem structuring methods such as the Soft Systems Methodology and Strategic Choice Approach are usually acknowledged. There are many methods dealing with quantitative investigation raging from static representation for instance, spatial mapping through public participation GIS, to more dynamic models such as System Dynamics (STELLA and VENSIM), Multi-Agent Systems (CORMAS and REPAST), Multi-Criteria Analysis (PROMETHEE methods), and Probability and statistical methods, such as Bayesian Networks (Daniell et al., 2006). Six case studies with different methods and tools used are analyzed and compared in the next section.

6.3. Comparison of Six Case Studies in the Field of Collaborative Modelling for RRM

This section presents the production collaborative modelling in six case studies under the RRM study domain. In the case of the qualitative method, causal loop diagrams were a main tool for a collaborative modelling conducted by Purnomo et al. (2003). These diagrams were used to establish relationships between key components, integrate different stakeholder perspectives, and agree on performance indicators of forest management in Indonesia. A cognitive map integrated with critical system thinking was used to develop a "facilitative device" in lower Mekong delta, Vietnam (Nico Hjortsø, 2004).

For the system dynamics, several studies have used system dynamics models to facilitate group discussion, particularly for data acquisition and decision support purposes (Gilbert, Maltby et al., 2002; Mayer and De Jong, 2004; Voinov and Gaddis, 2008; Winz et al., 2007). An increasing number of studies have adopted gaming, and computer simulation models, in particular the ABM, to facilitate social learning aimed at understanding current situations that has the potential to lead to better management decisions through a collaborative modelling process (Barreteau and Bousquet, 2000; Becu, Perez et al., 2003; d'Aquino, Le Page et al., 2003; Liu, Takeuchi et al., 2007). For the GIS-based collaborative modelling, Gonzalez (2002), Ranbalsi (2005), and McKinnon (2005) used GIS technology to integrate indigenous knowledge into a scientific one with a group of local stakeholders and GIS experts through participatory GIS map-generated development. These methods help to increase the participation of domain experts in the modelling process to support creative, interdisciplinary, collaborative exploration, and promote better designs. They also enable domain experts to validate that their domain is represented correctly in a conceptual model (Sullivan, 2004). Six case studies with different methods used in collaborative modelling are presented.

6.3.1. Cognitive Mapping and Soft Systems Methodology

The study site of the Damdoi Forest Enterprise (DFE) case was located in the lower part of the Mekong delta, Vietnam. Nico Hjortsø et al. (2005) studied the implementation of a buffer zone to protect against large-scale mangrove deforestation caused by the expansion of shrimp production and conflict between shrimp farmers and DFE over the establishment of a protected area. In this case study, the objective was to find a method to prepare facilitators of participatory inquiry and decision-making processes. This preparation and device produced was proposed to help facilitators obtain an in-depth understanding of the situation before conducting participatory activities. Eventually, the research team aimed to draw a buffer zone without critical conflicts with stakeholders. The Rapid Stakeholders and Conflict Assessment (RSCA) methodology, which integrates 4 methods— stakeholder analysis, conflict assessment, problem structuring, and critical system thinking—was used

The soft systems methodology was applied to structure the problem with participation of concerned stakeholders. The Cognitive mapping (CM) method (Axelrod, 1976; Mendoza and Prabhu, 2006a) was used to capture parts of the personal construct system by modelling the perceptions of each group member in a CM developed during interviews to represent the network of concepts (notes) used to form chains of argumentation. All CMs were produced by using the software package "Decision Explorer". A facilitator analyzed these maps to indentify clusters of related concepts and merged them into a "facilitative device" that was used in problem identification and negotiation.

In this case study, CMs were useful for capturing stakeholder perceptions, their sense of dependency on the natural resource system and their interactions with other stakeholder groups, including existing and potential conflicts. However, without a temporal dimension, CMs made it difficult for participants to explore their interesting scenarios. Besides, without the spatial dimension evolving through time, participants had difficulty pinpointing where the impact was worse that urgently needed to be look after.

6.3.2. System Dynamics

Tidwell et al. (2004) applied system dynamics[5] (SD) to plan community-based water management in the Middle Rio Grade, north-central New Mexico. The problem was the imbalance between water supply and demand in this semi-arid region, and lack of stakeholder involvement in making development plans. The objective was to create a water resources model for community-based planning. This SD model was proposed to enable participants to quantitatively explore alternative water management strategies, educate them on the complexity of the regional water system, and engage them in the decision process.

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[5] **System Dynamics (SD)** is a concept based on systems thinking where dynamic interaction between the elements of the system is considered to study the behaviour of the system as a whole. As the name suggests the behaviour of the system is monitored over time and is thus dynamic. The concept of SD was introduced by Forester (1961). The main idea of system dynamics modelling is to understand the behaviour of the system by the use of simple mathematical structures. SD concepts can help: (i) describe the system; (ii) understand the system; (iii) develop quantitative and qualitative models; (iv) identify how information feedback governs the behaviour of the system and finally, (v) develop control polices for better management of the system.

Causal loop diagrams were used to represent key elements influencing water supply and demand. The SD model was produced using Studio Expert 2001 and 2003. The model represents dynamics water budget as a result of interactions between surface and ground water stored in the basin varying annually in response to changes in the associated inflows and outflows. The model development process benefited from interactions with a community outside of the modelling team. The scientific knowledge was derived from water professionals and scientists. Public feedback from water forums, where various schools and universities, civic and professional groups participated, was integrated into the SD model. In this case study, SD provided a framework to integrate the disparate physical and social systems important to water resource management. The SD model was able to be used for interactive public engagement.

6.3.3. Multi-Agent Systems

The Multi-Agent Systems[6] (MAS) played a key role in "the participatory computer simulation to support collective decision-making" conducted by Becu et al. (2007) in Mae Sa watershed, Chiang Mai, northern Thailand. The problem was conflicts regarding water use between upstream and down stream villages as a result of water scarcity. The objective was to test the assumption that stakeholders can be confronted directly with an abstract computer model of human-ecosystem interaction. The research team also intended to use this abstract model as an explorative and decision-support tool to facilitate the negotiation over natural resources between stakeholders with conflicting interests.

The research framework of this case was one from the collaborative modelling family, the Companion Modelling (ComMod) approach (Barreteau, 2003a). An ABM

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[6] **Multi-Agent Systems (MAS)** originally came from the field of artificial intelligence (AI). At first, it was called distributed artificial intelligence (DAI). The objective was to reproduce the knowledge and reasoning of several heterogeneous entities called 'agent' that need to coordinate to solve planning problem. The coordination of actions or the construction of systems represents the consequences of interactions between relatively independents and autonomous agents operating within communities in accordance with what are sometimes complex modes of operation, conflict and competition in order to survive and perpetuate themselves. Organized structures emerge from these interactions, which in turn restrict and modify the behaviours of the agents. The characteristic of emphasizing interactions and, more precisely, of analyzing the interaction systems, which exist between agents is what distinguishes MAS from the more classical approaches, in that preference is given to emergence, and action and interaction are considered as the motor elements in the structuring of a system taken as a whole.

was built on the CORMAS platform by the modeller. This ABM was used as a tool to facilitate communication among stakeholders. Three successive rounds of participatory simulation workshops were organized to allow stakeholders to validate the model, and to engage stakeholders in the negotiation process about water allocation.

Simulation of water shortages stimulated knowledge acquisition. For instance, stakeholders found that the expansion of sweet pepper cultivation in the downstream village would solve the problem of water shortage in the village while a shift to gerbera in the upstream village would increase water shortages for both villages. However, due to the complexity of this ABM, it was difficult for stakeholders to familiarize, and to create a sense of co-ownership.

6.3.4. Multi-Criteria Analysis

Multi-Criteria Analysis[7] (MCA) was combined with participatory modelling to increase participation of local communities in forest management and make them realize the benefits from a forest through a resource-sharing program in the Mafungautsi Forest, Gokwe District of the Midlands, Zimbabwe (Mendoza and Martins, 2006b). The conflict of interests between state agencies trying to protect the forest and local communities exploiting the forest was a problematic issue. The research team attempted to carry out a group model building to develop a combined

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[7] **Multi-Criteria Analysis (MCA)** is a general approach dealing with problems that involve multiple dimensions or criteria. MCA's ability to incorporate multiple views from different stakeholders makes it an excellent tool for participatory planning and decision-making. MCA's ability to deal with mixed data add some rigor to what otherwise would be a highly subjective and qualitative planning and decision-making process. In a formal model, the decision-making problem can be described as:

Optimize $Z = f(\chi_1, \chi_2, \ldots, \chi_n)$ where $f(\chi_1, \chi_2, \ldots, \chi_n)$ is the objective function.

Formally, MCA is an extension of the problem described above, accommodating multiple objectives or criteria. That is, the problem can be described as follows:

Optimize $Z_1 = f_1(\chi_1, \chi_2, \ldots, \chi_n)$
Optimize $Z_2 = f_2(\chi_1, \chi_2, \ldots, \chi_n)$
Optimize $Z_k = f_k(\chi_1, \chi_2, \ldots, \chi_n)$ where $Z_1, Z_2, \ldots, Z_k$ are the different criteria.

Each criterion has varying degrees of importance. Each criterion must be measured, and their relative effects individually evaluated. MCA also provides the structured process, and the means to measure the cumulative impacts of all criteria. That is, MCA offers a systematic (organized and structured) and systemic (embracing individual and collective effects) procedure to measure and reflect not just individual effects, but also the cumulative impacts of all criteria.

MCA and SD model with all concerned stakeholders. Their assumption was that MCA can fill a gap in participatory modelling by offering the structuring and analytical capability to the open and collaborative nature of participatory modelling. As a result, the acceptable resource management alternatives among all concerned stakeholders can be obtained.

The participatory modelling process at the initial stage was carried out by using CMs in the Co-View software to produce a strategic planning 'SWOT' (Strengths, Weaknesses, Opportunities, and Threats including Indicators). Then, a SD model (stock and flow) was developed based on elements in the SWOT obtained from the CMs. The MCA and its projected values based on the impact of the action plan were produced by core participants (governmental officers and researchers), and applied to SWOT elements structured in the SD model.

Core participants grasped the potential of the simple model as an analytical tool that could help them in planning and in the decisions they have to make, often based only on intuition and past experiences. In the end, the participants were more confident in their ability to use the model in generating insights, especially with respect to impact assessments. However, a short-coming was the composition of the core group that may have minimized the possibility of divergent opinions, and increased the 'black box effect' on non-participating stakeholders leading to low potential for compromise. This was because none of the participants from local communities in the modelling process was indicated while the projected values were decided for MCA.

6.3.5. Probability and Statistical Method

In Sri Lanka, Cain et al. (2003) conducted a study to test a tool called a Bayesian Networks[8] (BNs) to see if it could be accessible to non-specialists and able to provide generic, flexible framework for the construction of a decision support system (DSS). The objective was to provide agricultural policy makers with a DSS so that they could

[8] **Bayesian networks (BNs)** were originally developed as a formal means of choosing optimal decision strategies under uncertainty. Bayesian Networks are composed of three elements (i) a set of nodes representing system variables, (ii) a set of links representing causal relationships between nodes, and (iii) a set of probabilities (one of each node) specifying the belief that a node will be in a particular state given the sates of those nodes which affect it directly (its parents). These are called conditional probability tables (CPTs) and can be used to express how the relationships between the nodes operate.

identify problems and assess feasible and practical farm management solutions for farmers working in the Deduru Oya river basin.

In this case study, BNs are assumed to be more accessible for non-specialists to analyze a complex system. This is because the conceptual model to produce BNs is presented in diagrams of cause-effect relationships for group discussion. In addition, BNs embedded with Bayesian probability theory (Jaynes and Bretthorst, 2003) allow subjective data elicited from stakeholders to be used together with more objective data. Therefore, stakeholders can construct BNs to represent their different perspectives, and facilitate discussion of contentious issues so that conclusions can be reached and solutions are acceptable to all parties.

Two participatory workshops with different types of participants, policy makers and farmers, were organized. Participants from the government were formed into 4 groups. Each was guided by a set of instructions and facilitated independently. The participants managed to construct BNs by themselves. Another workshop with participating farmers was organized into two sub-workshops held in different places. Instead of letting the participating farmers construct BNs by themselves, semi-structured discussion was used to elicit the information necessary for the facilitators to construct a BN flow diagram. Questions similar to those used with governmental participants were asked. Two BN flow diagrams, one produced during the government workshop and another one interpreted by facilitators in the farmer workshop, were compared. It was clear that none of the groups were immediately comfortable with expressing their logic diagrammatically. But none of them had difficulties in capturing their ideas in terms of variables (nodes) and giving quantitative states (values) to those variables.

A pitfall found in this experiment was the subjective assessments made by individual groups and simple specification of state in BNs that could contribute to misleading results.

6.3.6. Spatial Mapping

In 2002, Gonzalez carried out a joint learning GIS with multi-actors living and working in steep mountainous area in Ifugao province, The Philippines. This unique landscape with handcrafted paddy terraces (UNESCO World Heritage) is facing a decline in traditional workgroups to conserve the area as a result of labour migration, and unsuccessful development paths proposed by state authorities. The research objective was to integrate spatial analysis capability and people's knowledge of their own space to understand the current problematic issues, thus leading to group discussion about feasible and practical development.

The primary medium of this participatory design was conversation. Aerial-photographs (1951 and 1980) and SPOT image (20 m solution) were used for the participatory image interpretation. GIS-generated maps using ILWIS GIS software were operated with stakeholders. Shared GIS-insights with the stakeholders were developed and evolved into local learning.

The most important outcome of this study was the successful communication among stakeholders about the fragile space in which they live. This was necessary in striving for the collective management of a common space. This study demonstrated that a participatory approach in designing a GIS could provide tools to facilitate thinking, negotiation, active social construction of natural resources, and collective decision-making (joint learning, social learning or collaborative learning). However, the limitation of this method was the lack of a dynamic dimension. Since maps represented only a 'snapshot' of the dynamic process, they could not be used to analyze the changes in short discrete time step. Another short-coming was the expensive software and hardware including materials such as satellite images.

6.3.7. Analysis of Six Case Collaborative Modelling Studies

This section presents the production of an analysis of six collaborative modelling processes in RRM. These case studies were analyzed following a proposed integrative methodological framework developed by the members of the "CGIAR Challenge Program on Water and Food (CPWF) PN 25: Companion modelling for resilient water management[9]" project in 2008. This framework is based on the experiences of the CPWF-PN25 team who use a collaborative modelling, the so-called Companion Modelling (ComMod) approach to understand individual and collective decision-making processes and practices (Barreteau, 2003a; Bousquet, Barreteau et al., 1999). Two main categories were defined in this framework: (i) general description and the

[9] The detail of the CPWF-PN 25 project is provided at http://www.ecole-commod.sc.chula.ac.th.

structure of the modelling process, and (ii) participants and their involvement through collaborative methodological stages.

The general description was proposed to specify the goal(s) and output(s) of the collaborative modelling process. The analysis of the modelling process structure focused on: (i) key original characteristics, (ii) sequence of methodological steps, (iii) tools & techniques used, and (iv) mode of learning (Table 6.1). The second part was to reveal the type of participants and analyze their respective degree of involvement. Two keys, decision-maker and flow of information between stakeholders and modellers, were defined with 6 degrees of stakeholder involvement ranging from no direct interaction to total control (Table 6.2). The decision-controller refers to the one who decides which information should be transferred or exchanged at a specific stage. For instance, if 'Information' is the degree of involvement, it means that a modeller is transferring his/her information to stakeholders. These levels were analyzed at each of the predefined methodological stages from "problem identification" to "decision on next step".

Goals and outputs found in these case studies range from theoretical testing to RRM problem-solving through the development of different tools for either qualitative or quantitative method or combination of both methods. Tools and techniques used for each case are determined by the goals and outputs (Table 1). The sequence of methodological steps is similar in all cases. Their first step is to identify problems at stake, and gather information for the system identification. Then, the development of models is carried out with stakeholders (Table 1). Finally, models produced are used to reach the defined goals ranging from testing assumptions (Becu et al., 2007; Gonzalez, 2002), to developing a decision support system (DSS) leading to an action plan (Mendoza et al., 2006b; Nico Hjortsø et al., 2005; Tidwell et al., 2004), or combination of theoretical testing and DSS development (Cain et al., 2003).

Table 6.1 General description and the structure of the modelling process of 6 case studies.

Category	Method	Model produced	Problem	Goals and outputs	Structure of modelling process			
					Original characteristics	Tools and techniques	Sequence of methodological steps	Mode of learning
Qualitative	Cognitive Mapping and Soft Systems Methodology	• Thematic cognitive map	• Large-scale of mangrove deforestation	• Develop a facilitative device • Create a detailed understanding of different stakeholders' use of the mangrove	• Develop facilitative device through the integration of element of soft systems and critical system thinking with stakeholders' engagement in the modelling process.	• Stakeholder analysis • Conflict assessment • Problem-structuring (soft systems methodology): Cognitive map and qualitative questions • Critical systems thinking • Cognitive map software package "Decision Explorer"	• Gather information • Produce specialist cognitive map • Interview planning • Producsetakeholders' cognitive map. • Final analysis to carry out produce a new cognitive map for developing facilitative device	• Single loop learning: many participants involved during the problem identification, and exposure of the existing and potential conflicts but no further stakeholders' participation was organized.
Quantitative	System Dynamics	• Causal loop diagrams • A system dynamics (SD) model	• Imbalance between water supply and demand • Lack of stakeholder involvement in making development plan	• Create a water resources model to assist in community-based water planning	• Many presentations of interim versions of the SD model to allay the disparity in understanding between modellers and the public	• Causal loop diagrams and software package "Studio Expert 2001 and 2003" • Conceptual model represents dynamic water budgets of interaction between surface water and groundwater stored in the basin	• Define problem and the scope of analysis • Development of a description of the system in casual loop diagrams • Casual loop diagrams to system dynamics context conversion • Model review • The use of model by the public	• Multi-learning loop: different tools used (causal loop diagrams used to understand the system and a SD model used to explore scenarios). No furhter iterative participation was indicated.
	Multi-Agent Systems	• An agent-based model (ABM)	• The conflicts between upstream and down stream villages has took place as a result of water scarcity.	• Test assumption whether stakeholders can be confronted directly with an abstract computer model and use it for scenario exploration	• Direct confrontation of stakeholders with the ABM. • Examine the socio-political issues (on negotiation and collaborative decision-making) linked to the use of ComMod	• "Field work" for "primary data collection for model calibration". • "Field work" for subsequent interactions with stakeholders "to refine the model" during participatory simulation sessions • ABM as a tool to facilitate communication among stakeholders	• The Companion Modelling (ComMod) involves an iterative feedback loop ("field work" -> "modelling" -> "simulation") between researchers and stakeholders	• Multi-learning loop: three participatory sessions focusing on co-learning through collective discussion
	Multi-Criteria Analysis	• A model integrating Multi-Criteria Analysis (MCA) with system dynamics (SD) model	• Conflicts of interests between state agencies trying to protect the forest and local communities exploiting the forest	• Increase participation of local communities in forest management throguh a group model building	• A development of integrating MCA with SD model was conducted under participatory modelling process with iterative, cyclic and iterative within and among five steps process	• SWOT strategic planning and MCA • Cognitive mapping • A computer-assisted model called "Co-View software" to transform cognitive maps to a SD model	• Identification and exploration of the problem • Soft or qualitative value elicitation • Model building with implementation of MCA • Use of model with MCA capability • Development of an action plan	• Multi-learning loop: iterative modelling process to develop an action plan
	Probability and Statistical method	• Cause and effect relationship diagrams • Bayesian Networks (BNs) flow diagrams	• Agricultural policy makers need a decision support system (DSS) to identify problems and assess feasible and practical farm management solutions for farmers.	• Test BNs if it can be accessible to non-specialists and able to provide generic, flexible framework for the construction of a DSS.	• Enhance participatory analytical capacity by integrating a quantifiable tool (BNs) into participatory process to develop a decision DSS.	• Cause and effect relationship diagrams • BNs flow diagrams	• Identify the problems: Express problems as objects (nodes) • Give value to each problem object • Discuss potential solution objects • Give value to each solution object • Construct a diagram showing the cause and effect relationships • Discuss and give values to any other things that the proposed solutions will affect • Evaluate the likely degree of impact of each solution in numeric terms	• Single learning loop: local farmers • Multi-learning loop: government officers planed to reuse BNs model as a DSS.
	Spatial Mapping	• GIS map integrating folk GIS	• Decline of traditional workgroups to conserve the unique handcraft paddies terraces	• Integrate spatial analysis capability and people's knowledge of their own space.	• GIS makes available real-world data to others and help discuss and build a common view	• Aerial-photographs of 1951 (scale 1:40,000) and 1980 (scale 1:60,000) • SPOT image (20 m solution) • Scanned topographic map of Ifugao (scale 1:50,000) • ILWIS was the available GIS software.	• Step 1: Establishing boundaries • Step 2: Re-tracing the "water district" • Step 3: Participatory image interpretation • Step 4: Provincial link-up	• Single learning loop: No furhter iterative participation was indicated.

Table 6.2 Participants and their involvement in 6 case studies at each of the modelling stages.

Category	Method	Participant to modelling process			Degree of involvement						
		Selection method	Diversity	Number	Problem identification	Preliminary synthesis / diagnosis & data collection	First design of conceptual model	Model implementation	Definition of scenarios	Scenario exploration	Decision on next steps
Qualitative	Cognitive Mapping and Soft Systems Methodology	• Key institutions and informants involved in the planning and management of the zoning strategy	Damdoi Forest Enterprise (DFE)	2	4	4	4	4	4	4	na
			Coastal management specialists	2	4	4	4	0	4	4	na
			Government agencies	2	4	4	0	0	4	4	na
			Farmers (agriculture-fishery farming)	7	4	4	0	0	4	4	na
			Landless people	2	4	4	0	0	4	4	na
			Small-scale agriculture	1	4	4	0	0	4	4	na
			Fruit producer	1	4	4	0	0	4	4	na
			Bag-net fishermen	2	4	4	0	0	4	4	na
			Near-shore fishermen	2	4	4	0	0	4	4	na
Quantitative	System Dynamics	• Key institutions involved in the development of water planning model	Sandia National Laboratories (SNL)	na	0	0	4	4	4	4	na
			the Middle Rio Grande Water Assembly (MRGWA)	na	4	4	4	4	4	4	4
			the Mid Region Council of Governments (MRCOG)	na	2	2	0	0	4	4	na
			the Utton Transboundary Resource Center	na	0	0	0	0	0	5	na
			Public	na	0	2	0	0	4	4	na
	Multi-Agent Systems	• Farmers from upstream and downstream village, village headmen, representatives of the TAO and the manager of water company.	Northern Thai farmers / lowland irrigation water user	na	2	2	0	4	4	4	4
			Hmong ethnic farmers / upland irrigation water users	na	2	2	0	4	4	4	4
			Village households / domestic use of water	na	2	2	0	4	4	4	4
			Drinking water company / industrial use of water	na	2	2	0	4	4	4	4
	Multi-Criteria Analysis	• Based on at least 10 years working experience within the Mafungautsi Forest	District foresters	2	4	4	2	4	5	4	na
			Agricultural extension officer	1	4	4	2	4	5	4	na
			Social scientist	1	4	4	2	4	5	4	na
			Provincial officer	1	4	4	2	4	5	4	na
	Probability and Statistical method	• No specific criterion is provided for selection of state agencies. • The participating farmers were invited by field workers from the Department of Agrarian Services to represent the range of farmers and farming activities in the area.	The Irrigation Department	na	5	5	5	5	5	5	5
			The Department of Agrarian Services	na	5	5	5	5	5	5	5
			The Department of Agricultural Development Authority	na	5	5	5	5	5	5	5
			The Department of Forestry	na	5	5	5	5	5	5	5
			The National Water Supply and Drainage Board	na	5	5	5	5	5	5	5
			The Department of Public Administration	na	5	5	5	5	5	5	5
			Representatives from Pradeshiya Sabawas	na	5	2	0	0	0	0	na
			Farmers at the head of the basin	9	5	2	0	0	0	0	na
			Farmers at the tail of the basin	11	5	2	0	0	0	0	na
	Spatial Mapping	• No specific criterion is provided for participant selection.	Students	2	2	2	2	4	0	0	na
			Ifugao's farmers	6	2	2	2	4	0	0	na
			Ifugao provincial government board	na	2	2	2	4	0	0	na

na = not available

Degree of stakeholder involvement in modelling process: Bold character represents decision-controller. Arrow represents flow of information.
0 = No direct interaction 1 = Information [Stakeholder ← **Modeller**] 2 = Consultation [Stakeholder → **Modeller**]
3 = Co-thinking [Stakeholder ↔ **Modeller**] 4 = Co-designing [**Stakeholder** ↔ **Modeller**] 5 = Total control [**Stakeholder** ↔ Modeller]

In the CM, a single learning loop was found. Many participants were involved during the problem identification, and exposure of the existing and potential conflicts, in order to produce the facilitative device. In the case of the SD, multi-learning loop was likely to happen through many presentations of interim versions of the model. Multi-learning loop was also found in the MAS case because of the repeated use of the same model that was improved according to stakeholders' comments. In the MCA case study, multi-learning loop was generated because the iterative modelling process was conducted to develop an action plan.

Two learning modes were found in the probability and statistical method using BNs. The policy makers could be facilitated to use BNs to build a DSS while farmers could not. As a result, the policy makers planned to carry out more BNs experiments enabling them to have multi-learning loops. In the case of static representation of the system using GIS, the learning process was limited to only a single learning loop as a result of the difficulty in exploring future scenarios through the model produced.

The different types and degrees of stakeholder involvement in each modelling stage play an important role in justifying how far the selected method participating stakeholders are engaged in the modelling process. A synthetic illustration of six case studies was produced to address the relationship between types of stakeholders and degrees of their involvement at each modelling stage linking to the methods used (Figure 6.2). The participants were classified into decision-makers and lay people, or public involvement. Based on table 6.2, farmers and fishermen are considered as lay participants. Participants working for government or academic institutes are categorized as decision-maker participants. In the case of decision-maker participants, multi-degree of involvement was often found, for instance "no direct interaction" and "consultation" at problem identification stage. In such a case, only higher degree of involvement was kept; hence, "no direct interaction" was dropped off.

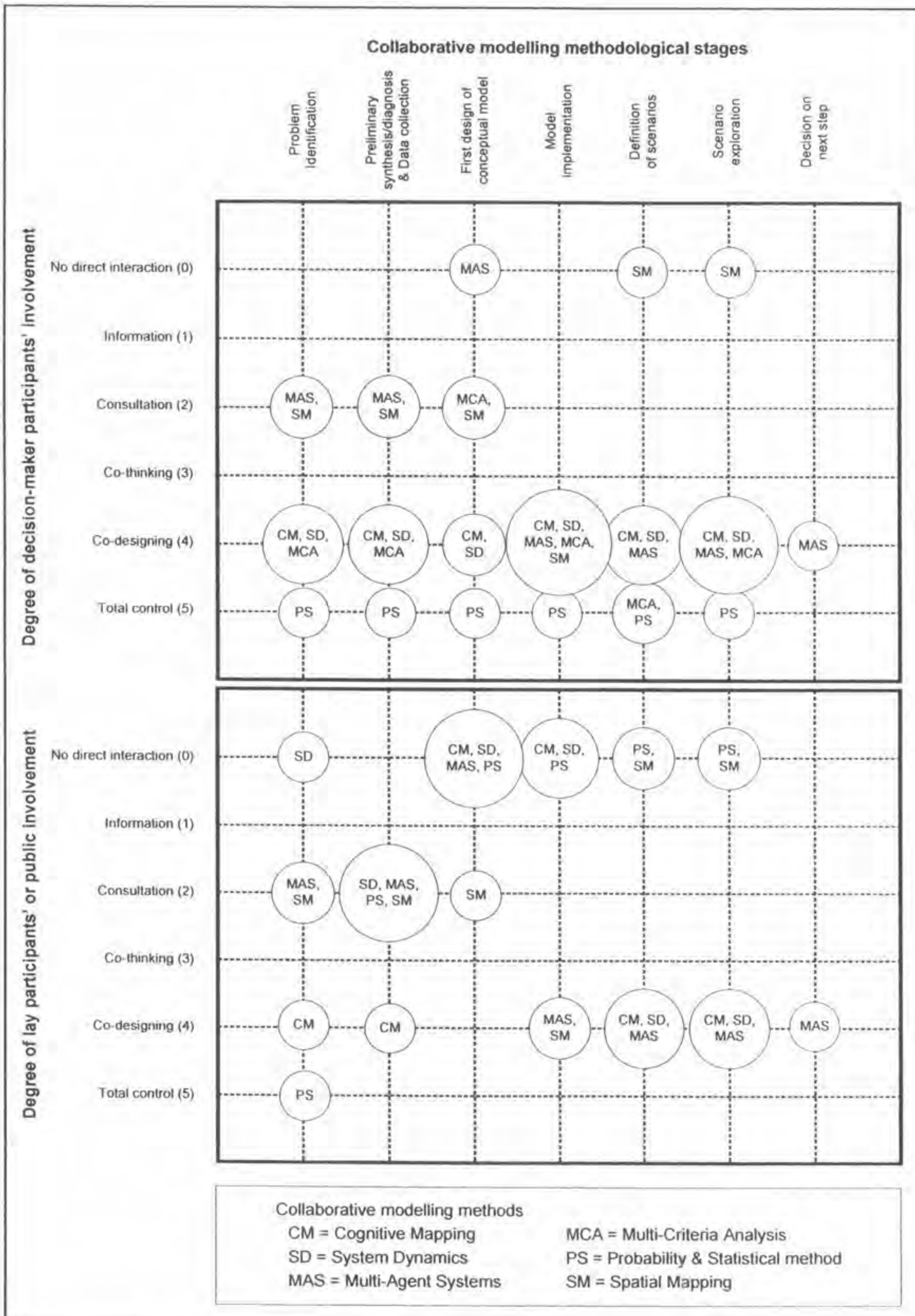

Figure 6.2 Relationship between types and degrees of stakeholder involvement in 7 collaborative modelling methodological stages found in 6 collaborative modelling methods.

In this analysis, lay people or public involvement is not identified in the MCA case study. Regarding the degree of involvement, the flow of information controlled by the modeller and the co-thinking defined as a two-way information flow controlled by the modeller are not presented in any case (see 'Information' and 'Co-thinking' in Figure 6.2). This indicates that the modellers had no absolute control in these six collaborative modelling processes. But the modeller can control which information is useful to be obtained. In this case, participants play a consultant role as found in the 'Consultation' (Figure 6.2).

Both lay and decision-maker participants of MAS and SM methods hold consultations to identify problems (problem identification). The consultation may indicate the need for modellers to better understand the context of problems prior to moving forward to the next stage. For other methods, participants engage in two way information flow either 'Co-designing' or 'Total control', whereby stakeholders are decision-controllers. Due to the simple causal diagrams found in the CM and range of variable values determined in probability and statistical methods (PS) using BNs, these features are not so difficult for the participants to engage in. Only the SD reported no direct interaction between the modeller and lay or public participants.

For the preliminary synthesis/diagnosis and data collection, the involvement of decision-maker participants is not different from the problem identification stage. For the lay participants, CM was used to get them involved at co-designing, while consultation was found in other methods. This may indicate that most collaborative methods are often used to gather data from lay participants at this modelling stage. During the problem identification and preliminary synthesis/diagnosis & data collection, the causal loop diagram is often used to structure problems derived from collective agreement among participating stakeholders. The joint use of CM, SD and MCA is an effective method. The CM is initially made on a piece of paper with simple casual diagrams while maps are used in SM. These features easily allow for lay people to get involved.

At the first design of a conceptual model, the decision-maker participants seem to have different degrees of involvement. However, it is different for the lay participants who are not involved (no direct interaction) in this stage except for SM. The non-participation of lay people at this stage may be caused by the difficulty of the tools used for communication with lay people (often computer software) when the initial conceptual model is produced. But the SM used maps, which are more easily understood by lay people.

Once the modelling process reaches the model implementation stage, the lay participants are often left out in all methods. Only MAS and SM is used with lay participants to implement the model by exchanging information with an equal amount of controlling power (both are decision-controllers). This is a critical stage that all participants should take part in as participation in this stage could help them to understand the model and lessen the "black box effect". The sense of co-ownership could also be effectively built through this stage. Furthermore, the model co-constructed with participants consistently proves its validity. This validity is important before moving to the scenario identification and exploration. With the simulation capability of methods such as MAS and SD, lay people are able to participate in defining scenarios and scenario exploration. Without simulation, CM is likely to stimulate participants' creativity through imagination in definition of scenarios and scenario exploration. Only the paper about MAS reported the next step (Decision on next step) decided by the modeller and participants. The MAS also shows all participants taking part in all stages equally. As a consequence, the gap between participants generated from partial participation is not likely to occur.

However, as stated by Asselt et al. (2002), there is no best method to conduct group model building; it is preferable to think about collaborative modelling as a flexible approach where a facilitator can make selections from a toolbox which contains many methods and tools to guide the process. In my case, the Companion Modelling (ComMod) approach is used. Throughout the process, the conceptual model representing interactions between land & water use and labour migration is enriched as a consequence of the development of associated tools, namely a Role-Playing Game (RPG) and ABM, with local participants. This ComMod process aims to enhance dialogue between researchers and participating farmers, integrate local and scientific knowledge, and build a shared representation of the system under study where researchers themselves pose as stakeholders in the system.