Successes And Failures Of Attempts To Embed Socioeconomic Dimensions In Modeling For Integrated Natural Resource Management: Lessons From Thailand

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EXTENDED ABSTRACT

This paper discusses the necessity, successes and failures of attempts to embed socioeconomic aspects into integrated natural resource modeling. It uses experiences in Thailand over the last 20-30 years to illustrate advances and difficulties in this integration. The paper highlights strengths, weaknesses and the effectiveness of different approaches which are used to incorporate socioeconomic dynamic processes and impacts. Lessons learnt from Thai experiences starting from systems thinking and approaches through to attempts to model agricultural and watershed systems for management are reviewed. Historically successes in integrating socioeconomic dimensions with biophysical analyses lie most often in interaction with agricultural and natural resource economists who have more experience dealing with quantitative methods and "hard" numerical approaches than other social scientists. The need for the "soft" side of assessment is recognized but is not easily realized. Failures to include the perspectives of anthropologists, psychologists and sociologists in integrated assessments have been caused by departmental boundaries, inadequate linkages between social theories and differences in the agendas of these fields. Different approaches to the treatment of socioeconomic variables and processes are highlighted. Modeling approaches, such as agent-based systems or multi-agent systems are more tuned to socioeconomic concerns but must first pass the test of acceptability by policy makers who are used to top-down, simplified approaches to solving problems. Balancing, or even better, integrating "hard" and "soft" systems approaches will improve the relevance and validity of the models to solve agricultural/natural resource problems.

1. INTRODUCTION

Attempts to include socioeconomic aspects in integrated modeling in agricultural and natural resource management started in the 1980s when soft systems methodologies and agroecosystem analysis were introduced (Checkland 1981, 1999, Checkland and Sholes, 1990, Conway, 1985). Farming systems research and extension (FSR/E) applied concepts of systems thinking and were a framework whereby agricultural scientists would incorporate socioeconomic data and variables into their assessments of options to improve these systems (Shanner et al 1982). This paper elaborates the development of integrated agricultural/natural resource modeling in the context of Thailand.

2. SYSTEMS APPROACH IN AGRICULTURAL AND NATURAL RESOURCE MANAGEMENT IN THAILAND

In Thailand, systems thinking in agriculture started in the 1980s with a network of Thai universities working with expatriates experienced in using systems approaches. Donors like the Ford Foundation, and the Canadian International Development and Research Center were keen to support activities which incorporated social science inputs in agricultural management. Chiang Mai University, Khon Kaen University, Kasetsart University and Price of Songkla University formed a network of agricultural researchers gearing their work and teaching towards a systems approach in agriculture. Conway's agroecosystem analysis, as well as FSR/E work including rural rapid appraisal (RRA) was also popular in the 1980s-90s among Thai researchers and practitioners (Ekasingh and Gypmantasiri, 1985). This systems approach has brought together many social scientists to work with natural scientists. Economists, agricultural economists, sociologists and anthropologists found their agricultural scientist colleagues much more interested in social issues and problems with this systems orientation.

Much work in the 1980s had the characteristics of "soft" system approaches. Problem situations were identified, conceptual models through systems diagrams were developed, stakeholders were consulted, and potential improvements to the systems were identified and implemented. Many agricultural scientists were very good facilitators, working intensively with villagers, identifying their problems and potential improvements.

In the 1990s and 2000s, more work in systems dynamics and hard systems approaches was forthcoming in the Thai context. This was due to the increased popularity of crop modeling in agronomy and farm household modeling and of impact modeling in economics. Increased attention was given to estimation of parameters and verification of models against the "real world."

One question relating to the reliance on these quantitative, model based approaches for Integrated Assessment (IA) concerns the role of social scientists in this "hard" systems approach, both in Thailand or worldwide. Sociologists and anthropologists were not involved substantially in these developments. Agricultural economists have been engaged in such work but still not to the extent necessary to embed social and economic concerns and perspectives in this research. The integration of "soft" and "hard" systems approaches, and of biophysical and social sciences, is crucial but often difficult to realise.

3. HARD AND SOFT SYSTEMS INTERFACE: A GAP IN KNOWLEDGE

There are fundamental differences in the two systems (hard vs. soft) approaches. Soft systems methods (SSM), like hard systems methods, are used to solve real-world problems by the application of system thinking. SSM emerged as an organized learning system. Grant and Thompson (1997) outlined some strengths and weaknesses of SSM. They state "the theoretical basis of linking and using these techniques (SSM) is learning theory rather than general systems theory.…there is in fact no methodological or theoretical reason to assume that the consensus actually reached in any given case will have anything to do with the systems studied through quantitative ecological models" (p.45). Nevertheless, soft system methods can be used by a skillful facilitator to help a diverse group lacking in technical knowledge arrive at a consensus plan for utilizing the knowledge of performance of a system that is produced by a quantitative model. Soft systems can be a way of eliciting information about attitudes and values that are crucial to the simulation of human dimensions within a quantitative model.

One frequently used hard systems approach, systems dynamics (SD), was developed in the late 1950s (Forrester,1961) The SD paradigm assumes that things are interconnected in complex patterns that can be captured by rates, levels and feedback loops. SD assumes that it is possible capture the high degree of detailed and dynamic complexity of the "real world" in a model without loss of relevance. The model is used to identify, through experimental simulation, appropriate levels of control variables to eliminate undesirable systems behaviour. Lane and Oliva (1998) argue that formal modeling aids in correctly representing and rigorously simulating a system— which is difficult to do within the human mind for anything but the most simple system representation. The concept of bounded rationality (Simon, 1957) means that "the human mind is not adapted to sending correctly the consequences of a mental model (Forrester, 1970)". As such model simulation is crucial in the system dynamics approach (Sterman, 2000).

Figure 1 displays a spectrum of approaches using "soft" interpretive modeling and "hard" quantitative modeling from Pidd (2003). This figure shows that for a constructivist approach, axiomatic interpretation of models is more important than the "reality" assumed and expressed in quantitative models. Nevertheless, both types of models are useful and in fact one needs to find a good balance between them for certain real world problems. Figure 2 displays the tendency of models normally built for natural science, economics and social science applications. Economists and agricultural economists generally apply equilibrium or optimizing models, based strongly on economic theory. Many critiques of these approaches can be found in the literature dealing mostly with their assumptions (see for example Roling, 1999; Moss et al., 2001) although these models have been found to be especially useful for regional planning (Letcher et al., 2005). More progress is being made to incorporate interactions and subjectivity in social modeling as reviewed by Bousquet and Le Page (2004).

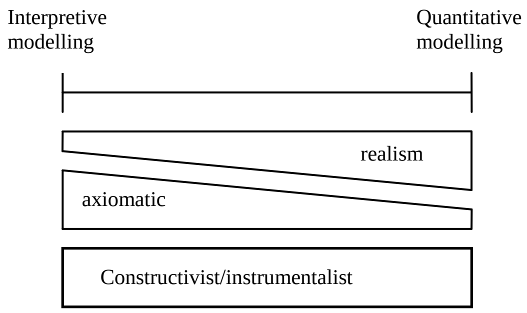

Figure 1: A sprectrum of approaches (Pidd, 2003)

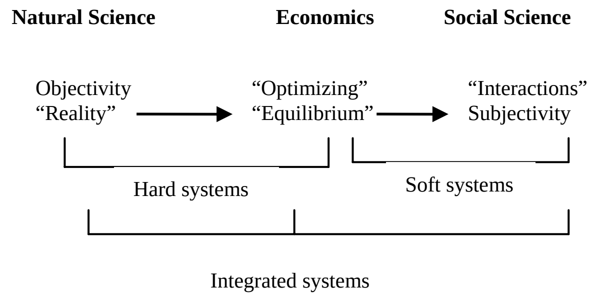

Figure 2 The make up of integrated systems

In Thailand, towards the 1990s, soft systems approaches, as practiced in AEA, RRA, PRA and FSR/E were losing their popularity, giving way to work in hard systems approaches such as crop and dynamic systems modeling, GIS-based modeling and scenario analysis. Some of the reasons for this trend were 1) the fatigue of problem-identification, 2) the need for more results- oriented solutions, 3) the need for more disciplinary rigor, and 4) progress in computer-based analysis and technology (see Appendix 1). However, integrated models of agricultural and natural resource management that apply the biophysical sciences to the same extent as the social sciences are rare. This is due to a variety of reasons, which include differences in the scales generally considered by these sciences. The social sciences generally focuses more heavily on smaller scale applications (such as smaller groups of farmers) which are not generally able to be accurately represented with biophysical models. Alternatively, social scientists are often unwilling or unable to deal with very large scales and aggregation over large groups of individuals. Methodologies that are able to reach a compromise between these scales and representations are required, as well as understanding of the limitations produced by such compromises. McIntosh et al. (2005) for example, call for such integration to occur.

4. INTEGRATED ASSESSMENT (IA) AND DECISION MAKING PROCESSES IN NATURAL RESOURCE MANAGEMENT

The need for an integration of models of different disciplines for tackling "real-world" problems of natural resource has been recognized and a growth in integrated natural resource management models has been well advanced in the literature (Scoccimarro et al, 1999; Merritt et al, 2004, 2005; Letcher et al., 2002; Jakeman and Letcher, 2003; Gilmour et al., 2005). Jakeman and Letcher (2003), for example, gave examples of developed and developing country experience (Australia and Thailand) and have outlined common features of integrated assessment in natural resource management. They stress the importance of IA as a process, not just as a set of outcomes. The environmental information systems (EIS) and computer-based decision support systems (DSS) resulting from IA work are ways of exploring and explaining tradeoffs, containing libraries of integrated data sets, models, methods, visualization and other tools. They are a forum for integration across researchers and stakeholders, as well as being useful tools for training and education and for facilitating adoption and adaptation by stakeholders.

Letcher et al. (2005) stress the importance of including social and economic sciences in IA work for natural resource management. The role of economics and social sciences is to recognize, understand and represent decision-making processes as well as the social and economic impacts resulting from changes in the natural resource system, including policy interventions, management strategies and variable climate forcing.

Moreover, economists and social scientists can better assist in designing and implementing participatory approaches to ensure greater stakeholder involvement in assessment and management. Decision making models that have been adopted so far in IA include regional-scale production models (Letcher et al., 2004; Hall et al., 1994; Branson, et al. 1998, 1999; Jayasuriya et al., 2001; Jayasuriya and Crean, 2000; Eigenraam, 1999), representative farm (household) models (Jayasuriya and Crean, 2001; Jayasuriya, 2000; Shinawatra, 1988), water demand models (Ringler, 2001; Renwick et al., 1998), agent-based models (Berger, 2001; Hood, 1999; Bousquet et al., 2001; Becu et al., 2001; Hare et al., 2001) and decision tree approaches (Ekasingh et al., 2005; Ngamsomsuk et al., 2005; Ashby and De Jong, 1982). Common impact models include input-output models (Horton, 2002; Woodlock, 1996; Fischer and Sun, 2001; Leistritz et al., 2002) and choice models (Morrison et al. 1996; Whitten and Bennett, 2001; Bennett and Morrison, 2001).

Economists usually make use of linear programming or goal programming to address farmers' or households' decisions. Assumptions are that farmers and households are rational and that their main objective is to maximize their income. More complex objectives can be handled in goal programming and multi-criteria decision analysis (Lee et al., 1995; El-Gayar and Ping Sun Leung, 2001).

New techniques are being investigated to tackle decision making problems. Data mining techniques are being explored to more easily capture decision making in the local context, making use of rich household-level data in developing countries (Ekasingh et al., 2005; Ngamsomsuke et al., 2005). Models of crop choice from data mining exercises for integrated watershed assessment in Northern Thailand were validated with field data achieving 95.8% and 86% accuracy for wet and dry seasons respectively (Ekasingh et al, 2005). In that study, land characteristics including soil type, as well as socioeconomic variables, such as costs of production, expected profit and land-labor ratio, were found to be useful in determining farmers' crop choices. Here, it was found that even without embedding any prior structure or knowledge in the decision tree relationships, the data mining technique reveals structures of decision making not too far from economic theories. Data mining does have weaknesses as far as theoretical underpinning in the social sciences is concerned but in certain situations, complex social systems can be simplified in a relatively easy and practical way using these techniques.

Economic models have been extensively criticized for their optimization or equilibrium-seeking assumptions (Roling, 1999; Moss et al., 2001). Moss et al. (2001) note that the interface between physical and social modelling has long rested on damage or response functions which either entered a cost benefit analysis or served as a target to measure the effectiveness of response strategies. These approaches, following standard economic modellling practice, imply greater predictability in the environment but do not allow for new behavioural patterns and social processes to emerge. The concentration on linear or equilibrium seeking relationships for representing both impacts and decisions, as well as the reliance on income or monetary benefits are often mentioned as weaknesses of these approaches. Roling (1999), Gilbert and Troitzsch (1999), Janssen (2002) and Moss (2001) have argued for more use of agent-based or multi-agent system (MAS) modeling which is more capable of dealing with social and political dimensions as it can capture interactions and relationships between agents as well as the importance of institutions. Participatory modeling or companion modeling using MAS has been developed to make modeling more participatory and help in a process of model validation (Bousquet et al, 2002, Bousquet and Trebuil, 2005, Moss et al 2001). Several models are being developed in Northern Thailand with promising results. These models are still used with relatively small groups of stakeholders (Trebuil et al 2002a, 2002b, Promburom, 2004, Bernard et al, 2005). Capacity to upscale to cover larger basin or watershed may be self-defeating as these models aim at capturing interactions between people and in this sense are better used in situations where the results of such interactions need to be highlighted. This may limit their use for larger scale applications.

Another integration approach that has promise for embedding social and economic perspectives in IA are Bayesian Decision Networks. These models capture the cause-effect relationships between state variables using conditional probabilities. They have been successfully used to incorporate social and economic impacts and attitudes to changes (see for example Ticehurst et al, in press; Ticehurst et al., 2005), as well as having been applied within a participatory modeling process. These approaches have been successfully applied in many countries (see for example Varis, 2002; Varis and Kuikka, 1999; Borsuk et al., 2004) but have yet to be adopted more broadly for IA in Thailand.

5. SUCCESSES AND FAILURES OF INCORPORATING SOCIAL SCIENCES IN INTEGRATED WATERSHED MANAGEMENT MODELING IN THAILAND

After two decades of attempts to embed socioeconomic perspectives in IA of agriculture and natural resources in Thailand, some successes can be claimed, largely within the agricultural economist profession. The inclusion of agricultural economists in the Faculty of Agriculture in many Thai Universities has been an important component of these successes. Bureaucratic boundaries among Thai departments have made it difficult for interdisciplinary work. Attempts to encourage close working relations between agronomists and agricultural economists in the Thai Ministry of Agricultural and Agricultural Cooperatives have proved unsuccessful when staff are from different departments with different mandates, politics and lines of command. In universities, departmental boundaries are still strong and anthropologists and sociologists have their own agendas. The Integrated Watershed Resources Assessment and Management (IWRAM) Project worked to build an interdisciplinary team to develop and use IA as a tool to assess the sustainability of several Thai watersheds (see Jakeman et al., 2005). This project had mixed experiences in embedding social scientists as part of the IA team. Only agricultural economists continued to be involved throughout the life of the project. Part of the reason for this was the inadequate inclusion of "soft" dimensions in this largely model-based assessment. These problems may be in part because of the relative youth of such IA methods. At the beginning of the IWRAM project, methods for engaging a broad group of scientists and social scientists across two cultures (Thai and Australian) were in a very early stage of development. Few of the team had any experience in working in such a group. As such distinct groupings occurred between which integration was in many ways easier to achieve (eg. between hydrologists and agronomists). In such a process it can be hard to see how a social scientist—a non-economist, can contribute in a meaningful and challenging way to such an assessment. Linkage between their social theory (in a broad sense) and practice is often not present. Without such a link, it is hard to make integrated work challenging to these groups. On the other hand, agricultural economists and economists are usually capable of dealing better with "hard" and "soft" system dimensions even though their work is usually entrenched in the assumptions of economic theory. While these assumptions can be questioned e.g. assumptions of rationality, profit maximization, linearity, homogeneity, etc, at least there are links to economic theory. Additionally the tools and methods of agricultural economists, specifically models, more closely resemble those of 'natural' scientists than the techniques employed by other social scientists.

In Thailand, there has been a growth in the use of multi-agent systems in recent years to overcome some of the weakness of economic assumptions. There are increasing numbers of social scientists involved in agent-based modeling and MAS work as these approaches use modeling capable of incorporating the theories of these disciplines (Janssen and de Vries, 1998, Jager et al 2000, Moss et al 2001). The concept of emergence, while essential in all system dynamics work, is particularly dominant in MAS especially when dealing with behavior and interactions between people. Collective action, issues of institutions, participatory processes and bottom-up "companion modeling" are highlighted applications of MAS (Bousquet and Le Page, 2004, Trebuil et al, 2002a,b, Bousquet and Trebuil, 2005). This approach and the associated methodology are still under development and are continually evolving. The impact of the application of these models to the solution of natural resource management problems is also yet to be demonstrated. The acceptance of this approach and methods by policy makers, who are used to top-down, simplified, broad-based cost-benefit approaches is yet to be tested.

Other model-based approaches are also becoming more sensitive to issues of participation and other social concerns. Ideally a mix of methods should be applied for different problems. A focus on process in assessment (see for example Jakeman and Letcher, 2003; Letcher et al., 2004; Letcher et al., 2003) means that the role of 'soft' systems approaches in IA can be more easily identified.

The systems work in the Multiple Cropping Center, Chiang Mai University has included GIS-based decision support systems (DSS) incorporating inputs from farmers, and costs and benefits from economists. Evaluations of agricultural and natural resource systems for planning purposes have also found economic inputs useful (Ekasingh, 2004, 2005). The system is currently a provincial DSS designed to be an open system capable of linking different sources of information from different departments and is simple to understand. Scenario and sensitivity analysis can be undertaken making use of biophysical and socioeconomic information. In this DSS, called DSSARM (DSS for Agricultural Resource Management), farmers' indigeneous knowledge in agriculture is also incorporated but by crop scientists—who by necessity turn themselves into community-workers-cum-researchers. Depth in the treatment of social dimensions is surely lost as these scientists are not trained in the methods of participatory research. Previous attempts at integrated research with social scientists on agriculture and natural resource management were not so successful. Interdisciplinary exchanges do take place but intellectual distance still dominates.

Participation is a concept that lends itself to all sciences. Participatory assessment is needed in IA, yet many "hard" models are too complicated for stakeholders to comprehend, particularly when they are presented early in the life of a project as 'final' products. Despite good principles of IA, as outlined by Jakeman and Letcher (2003), in practice these principles can prove to be hard to follow. Stakeholders, like provincial, district and sub-district officers, would most likely dismiss many models as being too mathematical and complex but would also often feel some parts have been too greatly simplified. Users of these models and IA are often experts and academics (McIntosh et al., 2005). The increasing use of "soft" system approaches can help to improve this situation at the same time as adding value to the "hard" models used in IA. Practitioners of participatory assessment are often biophysical scientists—turning themselves into participatory scientists (see for example Promburom, 2004, Bousquet and Trebuil, 2005). As practiced in the Thai context, failures to include anthropologists and sociologists are common in IA but this is not usually due to a lack of recognition of their importance. Better ways to work across disciplines, clearer objectives, and clearer expectations for differed groups are needed for successful integration of knowledge. Good leadership which can induce a balanced contribution between soft and hard sciences is also essential for such integrated work. As "hard" models are gaining ground in the 2000s, it is time to address the balance and bring back the "soft" models of the 1980s – using the best of both approaches according to circumstance and purpose - to improve the relevance and validity of models if we are seeking a truly balanced integration of perspectives.

References

Ashby, J. A., and G. de Jong (1982), Farmer field preparation and tillage practices. Implications for fertilizer technology research, *Soil and Tillage Research*, 2(4), 331-346.

Barnaud, C., P. Promburom, F. Bousquet and G. Trebuil (2005), Companion modeling to facilitate collective land management by Akha villagers in Upper Northern Thailand, Paper presented at the Conference on Sustainable Use of Natural Resource and Poverty Dialogue in Montane Mainland South East Asia (MMSEA IV), 16-19 May 2005, Sapa, Vietnam.

Becu, N., P. Perez, A. Walker, O. Barreteau and C.Le Page (2003), Agent based simulation of a small catchment water management in northern Thailand: Description of the CATCHSCAPE model, *Ecological Modelling* 170(2-3):319-331.

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

Borsuk, M.E., Stow, C.A., Reckhow, K.H., (2004). A Bayesian network of eutrophication models for synthesis, prediction and uncertainty analysis. Ecological Modelling 173, 219-239.

Bousquet, F., R. Lifran, M. Tidball, S. Thoyer and M. Antona (2001), Agent-based modeling, game theory and natural resource management issues, *Journal of Artificial Societies and Social Simulation.* 4(2) http://jasss.soc.surrey.ac.uk/4/2/0.html

Bousquet, F., O. Barretau, P. D'Aquino, M. Etienne, S. Boissau, S. Aubert, C. Le Page, D. Babin and J-P. Castella (2002), Multi-agent systems and role games: collective learning processes for ecosystem management, in M.A. Janssen (ed), *Complexity and Ecosystem Management: the Theory and Practice of*

Multi-Agent Systems. Cheltenham: Edward Elgar, pp. 248-85.

Bousquet, F. and C. Le Page (2004), Multi-agent simulations and ecosystem management: a review, *Ecological Modelling* 176: 313-332.

Bousquet, F. and G. Trebuil (2005), Synergies between multi-agent systems and role-playing grams in companion modeling for integrated natural resource management in Southeast Asia, In V. Kachitvichyanukul, U. Purintrapiban and P. Utayopas. eds. *Proceedings of the Symposium on Simulation and Modelling: Integrating Sciences and Technology for Effective Resource Management* held at Nakorn Pathom, Thailand, 17-20 January, 2005,

Branson, J, M. Eigenraam, G. Stoneham, J. Crean, P. Pagan (1998), Structural adjustment pressures in irrigated broadacre farming in the Southern Murray-Darling Basin. Natural Resource Management Strategy MDBC I&E Project No. I6041: Economic Services Unit, NSW Agriculture. Economic Branch, Dept. of Natural Resources and Environment (Vic).

Branson J, M. Eigenraam, G. Stoneham, J. Crean, P.Pagan (1999), Structural adjustment pressures in irrigated broadacre farming in the Southern Murray-Darling Basin. Final Report to the Australian Bureau of Agricultural Economics: NSW Agriculture and Victorian Department of Natural Resources and Environment.

Chambers, R. (1992), *Rural Appraisal: rapid, relaxed and participatory*, Institute of Development Studies Discussion Paper No. 311. University of Sussex: IDS.

Checkland, P.B. (1981), *Systems Thinking, Systems Practice*. Chichester: John Wiley & Sons.

Checkland, P.B. 1999. *Systems Thinking, Systems Practice: a 30 year Retrospective*. Chichester: John Wiley and Sons.

Checkland, P.B. and J. Sholes (1990), *Soft Systems Methodology in Action*. Chichester: John Wiley & Sons.

Conway, G.R. (1985) Agroecosystem analysis, *Agricultural Administration.* 20(1): 31-55.

Eigenraam M. (1999), Economic assessment of water market reform using the water policy model. Working Paper: Economics Branch, Division of Agriculture, Department of Natural Resources and Environment.

Ekasingh, B., K. Ngamsomsuke, R.A. Letcher and J. Spate (2005), A data mining approach to simulating land use decisions: modelling farmers' crop choice from farm level data for integrated water resource management, In V. Kachitvichyanukul, U. Purintrapiban and P. Utayopas. eds. *Proceedings of the Symposium on Simulation and Modelling: Integrating Sciences and Technology for Effective Resource Management* held at Nakorn Pathom, Thailand, 17-20 January, 2005, pp.327-335.

Ekasingh, M. (2004), Scenario analysis in decision support systems in agriculture." Proceedings of the 3rd National Symposium in Agricultural Systems. Chiang Mai. (in Thai)

Ekasingh, M. ed. (2005), Decision support system for planning for agricultural resources in upper north phase I :progress report submitted to Thailand Research Fund.

Ekasingh, M. and P. Gypmantasiri (1985), Use of agroecosystem analysis for area study and research identification, In Proceedings of in the 2nd Farming Systems Symposium. Khon Kaen. 3-5 April 1985, p.53-76. (in Thai)

Forrester, J. (1961), *Industrial Dynamics.* Cambridge: MIT Press.

El-Gayar, O. F. and Ping Sun Leung, 2001. "Multi criteria decision making framework for regional aquaculture development." *European Journal of Operation Research*. 133: 462-482.

Forrester, J. (1970), Counterintuitive behavior of social systems. Collected Papers of Jay W. Forrester. Cambridge, MA: Wright-Allen Press.

Gilbert, N and K. Troitzsch (1999), *Simulation for the Social Scientist*, Open University Press. Milton Keynes.

Gilmour, J.K., R.A. Letcher and A.J. Jakeman (2005), Analysis of an integrated model for assessing land and water policy options, *Mathematics and Computers in Simulation* 69(1-2):57-77.

Grant, W. E. and P.B.Thompson (1997), Integrated ecological models: simulation of socio-cultural constraints on ecological dynamics, *Ecological modelling* 100 (1-3): 43-59.

Hall, N., D. Poulter, and R. Curtotti (1994), ABARE model of irrigation farming in the Southern Murray Darling Basin. Research Report 94.4. Canberra: ABARE, 1994.

Hare M, P.Deadman and K.Lim (2001) Towards a taxonomy of agent-based simulation models in Environmental Management. In: Proceedings of the International Congress on Modelling and Simulation (MODSIM2001), Canberra, Australia, 2001;1115-1122.

Hood, L. (1999), Agent Based Modelling, vol 2002: Bureau of Rural Sciences.

Horton, G.A. (2002), Glossary of Selected Terminology Relating to Input-Output (I-O) Models and Economic Impact Analysis, vol 2002:Nevada Division of Water Planning.

Fischer, G., and L. Sun (2001), Model based analysis of future land-use development in

China, *Agriculture, Ecosystems and Environment* 85, 163-176.

Jakeman, A.J. and R. Letcher (2003), Integrated assessment and modelling: features, principles and examples for catchment management, *Environmental Modeling and Software* 18, 491-501.

Jager, W., M.A. Janssen, H.J.M. De Vries, J. De Greef, C.A.J.Vlek (2000), Behaviour in common dilemmas : *Homo economicus* and *Homo pyschologicus* in an ecological-economic model, *Ecological Economics* 35 : 357-379.

Jakeman, A.J., R. Letcher, S. Rojanasoonthon and S. Cuddy. eds. (2005), Integrating knowledge for river basin management. Australian Centre for International Agricultural Research.

Janssen, M.A. ed. (2002), *Complexity and Ecosystem Management: the Theory and Practice of Multi-Agent Systems*. Cheltenham: Edward Elgar.

Janssen, M.A. and H.J.M. de Vries (1998), The battle of perspectives: a multi-agent model with adaptive responses to climate change, *Ecological economics*. 26(1), 43-65.

Jayasuriya, R, J. Crean , R.Jones (2001), *Evaluation of Environmental Flow Rules in the Murrumbidgee Valley*. In: 45th Conference of the Australian Agricultural and Resource Economics Society, Adelaide, 23-25 January 2001.

Jayasuriya, R. and J. Crean (2000) The agricultural impacts of environmental flow rules in the Murrumbidgee Valley. Report to the Murrumbidgee River Management Committee. Orange: Economic Services Unit, NSW Agriculture.

Jayasuriya, R, J. Crean (2001), The on-farm impacts of environmental flow rules in the Murrumbidgee Valley. Report to the Murrumbidgee River Management Committee. Orange: Economic Services Unit, NSW Agriculture.

Jayasuriya, R. (2000), The on-farm impacts of groundwater management scenarios in the Lower Murrumbidgee. Report to the Murrumbidgee Groundwater Management Committee. Orange: Economic Services Unit, NSW Agriculture, 2000.

Lane, D. C. and R. Oliva (1998), The greater whole: towards a synthesis of system dynamics and soft systems methodology, *European Journal of Operational Research* 107:213-235.

Lee, D. J., T. Tipton and Ping Sun Leung (1995), Modelling cropping decisions in a rural developing country: a multiple-objective programming approach, *Agricultural Systems* 49: 101-111.

Leistritz, F. L., J.A. Leitch, and D.A. Bangsund (2002), Regional economic impacts of water management alternatives: the case of Devils Lake, North Dakota, USA, *Journal of Environmental Management*, 66, 465-473.

Letcher, R.A., W.S. Merritt, A.J. Jakeman, B.F.W. Croke and P.Perez (2002), An integrated toolbox for water resources assessment and management in Northern Thailand. In: A.Rizzoli, A.Jakeman. (Eds.), *Proceedings of the International Environmental Modelling and Software Society (iEMSs 2002)*, Lugano, Switzerland, June 24–27 2002, vol. 3, pp. 97–102.

Letcher, R. A., A.J. Jakeman, and B.F.W. Croke (2004), Model development for integrated assessment of water allocation options, *Water Resources Research*, 40, W05502.

Letcher, R., B. Ekasingh and K. Ngamsomsuke (2005), Modelling socioeconomic impacts and decision processes, In A. Jakeman, R.A.Letcher, S.Rojanasoonthon and S. Cuddy. eds. (2005), Integrating knowledge for river basin management. Australian Centre for International Agricultural Research.

Merritt, W.S., B.F.W. Croke, A.J. Jakeman, R.A. Letcher and P. Pere. 2004. A Biophysical toolbox for assessment and management of land and water resources in rural catchments in Northern Thailand, *Ecological Modelling* 171(3):279-300.

Morison J and Zorzetto A. (1995), The economic impact of irrigated agriculture in the Namoi Valley region: Department of Land and Water Conservation, Water Resources.

Morrison M.D, R.K.Blamey, J.W. Bennett and J.J.Louviere (1996), A comparison of stated preference techniques for estimating environmental values. Choice Modelling Research Reports Research Report No. 1. Canberra: The University of NSW.

Moss, S. , C. Pahl-Wostl, T. Downing (2001) Agent-based integrated assessment modelling: the example of climate change, *Integrated Assessment* 2, 17-30.

Mcintosh, B. S., P. Jeffrey; M. Lemon and N. Winder (2005), On the design of computer-based models for integrated environmental science, *Environmental Management* 35(6): 741-752

Ngamsomsuke, K., B. Ekasingh and R.A. Letcher (2005), Crop choice simulation model for integrated water resource assessment and management, In V. Kachitvichyanukul, U. Purintrapiban and P. Utayopas. eds. *Proceedings of the Symposium on Simulation and Modelling: Integrating Sciences and Technology for Effective Resource*

Management held at Nakorn Pathom, Thailand, 17-20 January, 2005, pp.336-344.

Gypmantasiri, P. (2005), Keynote address. Multiple Cropping Center Annual workshop.

Promburom, P. (2004) Participatory multi-agent systems modeling for collective watershed management: The use of role playing game, *Proceedings of the 2nd International Conference of the European Social Simulation Association*, September 16-19, 2004.

Pidd, M. (2003), *Tools for Thinking: Modelling in Management Science*. 2ed. Chichester: John Wiley & Sons.

Renwick M, R. Green, C. McCorkie (1998), Measuring the price responsiveness of residential water demand in California's urban areas: Report prepared for California Department of Water Resources.

Ringler, C. (2001), Optimal water allocation in the Mekong River Basin. Discussion Papers on Development Policy 38. Bonn: Centre for Development Research, University of Bonn.

Roling, N. (1999), Modelling the soft side of land: the potential of multi-agent systems, In Leeuwis, C. ed. *Integral Design: Innovation in agriculture and Resource Management*. Mansholt Studies 15. Wageningen: Mansholt Institute.

Scoccimarro, M., A.Walker, C.R.Dietrich, S.Y.Schreider, A.J. Jakeman, and H.Ross (1999), A framework for integrated catchment assessment in Northern Thailand. iCAM Working Paper 99/1.

Shanner, W.W., P.F. Phillipp, and W.R. Schmehl (1982), *Farming Systems Research and Development: Guidelines for Developing Countries*. Boulder: Westview Press.

Simon, H. (1957), *Administrative Behavior: a Study of Decision-Making Processes in Administrative Organizations*. 2nd. New York : Macmillan.

Shinawatra, B. (1988), Representative farm decision making model for oilseed crop development, *Warasarn Kaset* 4 (1), 1988 : 69-81. (in Thai)

Sterman, J. D. (2000), *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Boston: McGraw-Hill.

Ticehurst, J.L. L.H. T. Newham, D. Rissik,, R.A. Letcher, and A.J. Jakeman (in press), A Baysiean network approach to assess the sustainability of coastal lakes, Journal of Environmental Modelling and Software.

Ticehurst, J.L., Rissik, D. Letcher, R.A., 1Newham, L.H.T., and Jakeman, A.J., (2005), Development of Decision Support Tools to Assess the Sustainability of Coastal Lakes, Proceedings of the International Conference on Modelling and Simulation (MODSIM05).

Trebuil, Guy, C. Baron, F. Bousquet and B. Shinawatra-Ekasingh (2002a), Collective creation of artificial worlds can help govern concrete natural resource , International Symposium on Sustaining Food Security and Managing Natural Resources in Southeast Asia: Challenges for the 21st Century. , 8 - 11 January 2002, Chiang Mai, Thailand.

Trebuil, G., B. Shinawatra-Ekasingh, F. Bousquet and Charal Thong-Ngam (2002b), Multi-agent systems companion modeling for integrated watershed management: A Northern Thailand Experience, Paper presented in the 3rd Montane Mainland Southeast Asia Conference, Lijiang, Yunnan, China 25-28 August 2002.

Varis, O. (2002). Belief networks: generating the feared dislocations. In: Beck, M.B. (Ed.), Environmental Foresight and Models: a manifesto. Elsevier 500 pp.

Varis, O., and Kuikka, S., (1999). Learning Bayesian deision analysis by doing: lessons from environmental and natural resources management. Ecological Modelling, 119: 177-195.

Whitten, S.M., J.W.Bennett (2001), Non-market values of wetlands: A choice modelling study of wetlands in the Upper South East of South Australia and the Murrumbidgee River floodplain in New South Wales. Private and Social Values of Wetlands Research Reports Research Report No. 8. Canberra: The University of New South Wales.

Whitten, I.H. and E.Frank (1991), *Data Mining: Practical Machine Learning Tools and Techniques with Java Implementations*, Morgan Kaufmann Publishers, pp.265-320.

Woodlock A. (1996), The impact of interim river flow objectives on the regional economy in the Namoi Region. unpublished report submitted to the River Flow Objective Working Group. Parramatta, NSW: Department of Land and Water Conservation.

Appendix 1 Evolution of systems approach at the Multiple Cropping Center, Chiang Mai University, (adapted from Gypmantasiri 2005)