1. Introduction

The potential of computer-based models as a source of advice for tackling management problems was well established with the concept of the decision support system or DSS (Sage, 1991, in McIntosh et al., 2007). This potential was also recognized within the land use systems research community. As a result, a large number of computer-based models and tools have been produced over the past decade with the aim of providing support to land use policy and management (e.g. Van Keulen, 2007; Rossing et al., 2007; Argent, 2004; Oxley et al., 2004). A number of studies of effective mobilization of scientific computer models were reported for a diverse range of users, such as farmers and policy makers (e.g. Meinke et al., 2006; Carberry et al., 2002; ISNAR, 2004, pp. 41–48; Zadoks, 1989). Here, we adhere to the definition of effectiveness of Cash et al. (2003): “[..] impacts on how issues are defined and framed, and on which options for dealing with issues are considered, rather than only in terms of what actions are taken to address environmental problems.” All those that reported effective efforts of mobilizing scientific computer models involved two actors, a scientific and a societal stakeholder (group). However, land use systems research addresses issues, such as agricultural policy making, land use planning and integrated water management, that often involve multiple stakeholders. There are few reports of effective use of tools in those situations involving multiple stakeholders. One of the few examples concerns the political debate about climate change. Shackley
(1997) concluded that climate models were instrumental in establishing the issue of climate change on national and international policy agendas.

Several potential roles for models in multi-stakeholder situations have been identified, such as: a heuristic role, improving understanding; a symbolic role, putting an issue on the political agenda; and a relational role, creating a community (McIntosh et al., 2005; Van Daalen et al., 2002; Shackley and Wynne, 1995). Shackley (1997) suggests that computer models can have these roles because models are “efficient ways of reducing complexity through synthesizing and integrating knowledge, and hence of generating and legitimating a commonly held story line, e.g., beliefs about the causes and effects of a phenomenon, about the possible ameliorative actions and also about the allocation of responsibility for the issue”. These story lines serve as a sort of ‘social glue’, helping to hold together a range of actors, with divergent goals and interests (Hajer, 1995). With this analysis, Shackley provides an answer to why in particular computer models are suited for those roles. However, the few reported examples of effective use of a tool in a multi-stakeholder context do not provide the theoretical and/or empirical material to understand how computer models get to perform their heuristic, symbolic and relational roles. Therefore, the aim of the work reported here is to build critical understanding of how models harness land use modelling to perform heuristic, symbolic and relational roles in multi-stakeholder contexts. Thereto, a conceptual framework of the interactions between scientist, model, and societal stakeholders is developed (Section 2).

Subsequently, this framework is used to analyse three cases of linking land use modelling to problem solving in a multi-stakeholder context (Section 4). The land use models concerned have all been described in peer-reviewed journals. The methodology is introduced in Section 3. Our discussion (Section 5) is meant to be suggestive rather than conclusive, providing a partial analysis of the cases at hand, as well as outlining an approach to future case studies.

2. A conceptual framework of the interactions between scientist, model, and societal stakeholders towards solving a problem

The variety in computer-based models and tools has generated lively debate in recent years about the appropriateness of specific models, and the question of which type of model provides the best tool for the job (e.g. Matthies et al., 2007). Earlier publications have discussed ‘critical success factors’, such as the representation of uncertainties in computer models, the need for proper timing, the ease of use of graphical user interfaces and transparency (e.g. Mysiak et al., 2005; Oxley et al., 2004; Saloranta et al., 2003). However, as argued in Section 1, those analyses provide few clues on how model development and application are to be arranged. We found that the sociology of science offers a useful basis to address this ‘how’ question, i.e. to link model development and application-related features, such as possible research arrangements, conditions and model qualities, to the roles a land use model gets to perform. Sociologists of science argue that opinions about a model emerge from a complex interplay of scientific, social, institutional, policy and material factors. Concerns about, for instance, transparency are not the cause of disputes about models, nor just its effect, but rather an integral part of decisions and practices which change over time and space (Van Daalen et al., 2002; Shackley, 1997). What is the ‘best tool for the job’ eventually is decided in interaction. In this section, we use those and other insights from the sociology of science to develop a conceptual framework to understand how models become effective in a multi-stakeholder context.

2.1. Actor Network Theory

Societal problem solving in a multi-stakeholder context, in the remainder of this paper referred to as ‘complex problem solving’, is about coping with different backgrounds, interests and opportunities, and with sometimes completely different perspectives of both problems and solutions. These perspectives imply specific interpretations of realities and the responses to these, constructed by the actors involved according to their backgrounds and interests (Weick, 1995; Koppenjan and Klijn, 2004). Conflicts of interest are likely to emerge wherever actors strive for meaningful change (Leeuwis, 2000). In such cases, problem solving requires negotiation as well as social learning. Here, social learning is about the recognition of mutual dependencies between the actors that are involved in the problem at stake (Bouwen and Tailieu, 2004). Social learning and negotiation imply interactions between actors. To understand the roles of computer models in such contexts, actor network theorists argue that the computer model, as a non-human entity, should not be excluded from the analysis of those interactions beforehand (e.g. Callon, 1986; Latour, 1987). Actor Network Theory looks at the state of affairs in an action arena as the effect of interactions amongst human and non-human entities. A key element of this approach is that the patterns of interactions by ‘actor networks’ are composed not only of people, but also of machines, animals, money and so on because artefacts and natural phenomena have an influence on how human beings behave in a given context. A machine may perform certain tasks and hence ‘act’ in a particular way, and at the same time it structures human behaviour. That is, people must also act in particular ways if they want the technology to work. In the framework of our search for better understanding of how land use models become used, Actor Network Theory is relevant for another reason as well. Actor Network Theory explicitly addresses the process of incorporation of an entity in a network (Callon, 1987). Thus, the question of how an entity, such as a computer model, becomes accepted by the other actors. In Actor Network Theory, the strategies and methods for building and maintaining a network, are referred to as methods for ‘translation’. Translation can be described as a multi-faceted interaction in which actors (1) construct common definitions and meanings, (2) define and distribute roles, and (3) enrol each other as well as new people and things in the pursuit of individual and collective objectives (Callon, 1986). Consequently, objectives as well as the strategies to achieve them are not fixed in the network, but are continuously re-ordered as new people and things enter the arena.

2.2. Contextualization of scientific knowledge

This paper investigates and discusses the roles of land use models that were initially developed as research tools. However, even though these models are science-based, their contents are not neutral. Similar to the input of other actors, scientists’ questions, concerns and conclusions are not neutral (see e.g. Latour, 1987; Knorr-Cetina, 1981). Working in science, the experience of a researcher usually becomes ‘objectified’ by being transformed into peer-reviewed publications. In this transformation process, the researcher approaches the stance of an “ideal” observer so that this “objective experience” in principle, can be shared with and criticized by any member of the scientific community. When science plays a role in the world it studies, however, the claim of objectivity accompanying this scientific procedure of ‘objectifying’ often appears problematic (Carolan, 2006). What is perceived as objective within the scientific system does not need to be perceived as such outside this system because, similar to other social systems, power and interests play an influential role in science. Therefore, Alroe and Kristensen (2002) proposed to redefine scientific
objectivity; “[…] not the conventional, un-reflected objectivity, which excludes the intentional and value-laden aspects of science, but a reflexive objectivity that includes these aspects and exposes their role.” In a complex problem solving context, however, the scientific perspective not only needs explication of underlying values and aspirations, but frequently also needs the fitting to a social and biophysical context as well as interpretation in relation to other knowledge sources such as rules of thumb, or the experiences of other actors, to become effective knowledge (Carolan, 2006; Cash et al., 2006; Eshuis and Stuiver, 2005). In the remainder of the paper the combination of explanation of values and aspirations, fitting to context and interpretation of model work in relation to other knowledge sources is referred to as ‘contextualization’. Shackley’s (1997) analysis of why computer models are enrolled in policy processes illustrates the relevance of contextualization. He found that scientists and policy makers were involved in continuously adjusting their expressed or implied expectations, requirements, opportunities and constraints during the construction of a computer model. The end result was a product of mediation (including accommodation with ‘reality’, through the scientists’ perceptions of natural resistances). He concluded that this product of mediation appeared an important means through which coalitions began to take shape. If the model had not been mediated, or, in other words, contextualized, it is likely that research would not have contributed to the shaping of coalitions.

2.3. A conceptual framework

Fig. 1 is an attempt to capture the actors and interactions discussed above. The network is nested in a problematic biophysical and socio-economic context (the large ellipse). The problematic context is a driving force for the activities that are developed through the network. We distinguish five major actors in the network for our specific area of interest, i.e. linking land use modelling to problem solving in a multi-stakeholder context. These five actors are ‘science model’, ‘non-human entity’, ‘scientist’, ‘user’ and ‘other stakeholder’. All five actors in the network context are directly or through another actor connected to the other four actors in the network through their activities related to the land use problem at stake. A science model can only perform a role in complex problem solving when it is enrolled in the interactions by one or more of the users. It then gets a different status because it becomes part of the interactions, is contextualized and its role is being defined. This process of enrolment is highlighted in Fig. 1 by the ‘actual roles played by science model’ ellipse. Through its roles the model may have impacts in and outside the network. The non-human entity refers to possible other non-human features than the model, such as the meeting place, that are part of the interactions. The scientific stakeholders are referred to as scientists and the non-scientific actors as (societal) stakeholders. Here, scientists are people who relate to the land use problem in question through research activities; they can work at universities, institutes or e.g. policy agencies. Societal stakeholders are people affected by the land use problem in question. Pertaining to the contribution of a computer model, two groups can be distinguished within the societal stakeholders category: users and other stakeholders. Users are persons, groups, or corporate entities who have an interest in the problem and introduce the output of model simulations in the problem-related interactions. Other stakeholders also have an interest in the problem solving process at hand but do not bring in model output.

The conceptual framework in this Section was developed to address the question of how computer models come to contribute to complex problem solving and get specific roles. We used the conceptual framework to elaborate this main question in three subquestions to further investigate the issue in three case studies:

1. What role(s) did the model play in the course of the interactions?
2. How did the model become part of the interactions in the network?
3. Which model qualities contributed to the actual role(s) of the model?

The first two questions relate to the conceptualization of effective model application as presented in this section, i.e. a land use model becomes part of the interactions in a network, is contextualized and gets a role. The last question is about which specific features of land use models add to the translation methods of a network, i.e. the methods and strategies to build and maintain a network.

3. Methodology

The three studied models are referred to as GOAL, EURURALIS and TOA. Through literature and oral hunts, these three cases with claimed impact were identified. Table 1 lists the written material studied that is not in the reference list. The purpose of our research was to deepen our understanding, to develop a conceptual framework and to explore its value, not to already test it on a large scale. We would have wished for more cases, but it was very hard to find cases of which we were reasonably sure that they had had impact and of which actors could be interviewed. In all three identified cases, researchers from Wageningen University & Research Centre were involved. The case analyses were constructed from data from semi-structured interviews, official and internal reports, grey literature and journal articles. In the interviews and study of written material, three main themes were related to: (1) the actual roles played by the model, e.g. how was the model used, on which occasions, and perceived changes in use over time; (2) the network-related problematic biophysical and socio-economic context, e.g. arguments for developing the particular land use model, the context in which the model became used; (3) the network, e.g. the other stakeholders, users, scientists and other non-human entities interacting with the land use model, the character of the interactions between these network actors. There were no opportunities to observe interactions as two cases took place at the beginning of the 1990s, and in the third case, a meeting of users and stakeholders was postponed until a couple of months after our research period. In total, 13 persons were interviewed (i.e. GOAL 4, EURURALIS 5, TOA 4) nine out of the 13 more than once, three responded via e-mail, the oral interviews lasted on average 1 h each. The respondents of the respective cases represented the different actor groups involved in the problem at stake, i.e. modellers, users, and other stakeholders. This section was thereafter checked for factual mistakes by the respondents. We would have preferred to question more persons, but non-response was high, in particular in the ‘other stakeholder’ category. However, we feel that the three cases
together provide adequate material to develop suggestions and hypotheses about how to effectively harness land use modelling for problem solving in multi-stakeholder contexts. Through the combination of data from interviews and documents and the check by a number of the respondents, some rigour and quality assurance was achieved. Deviant information from a particular source could always be explained through revisiting other information sources. We deem the risk of a bias in the data because of the relatively low response of other stakeholders rather limited. We considered the response of ‘users’ more relevant than that of the ‘other stakeholders’ category addressing our particular research questions.

Obviously, to research how a land use model came to play a role in complex problem solving, the model needed to have had some kind of impact. Impact was defined as noticeable reactions outside the scientific networks. It was not the purpose of the reported research to prove or evaluate the reach of impact in the case studies. Therefore, if none of the respondents objected to a claimed impact and we did not find any clues in the literature invalidating the claim, it became a starting point for the field work. The three possible roles of land use models, i.e. heuristic, symbolic and relational, were made operational to create a further basis for the data analysis. Explicit reference to learning as well as reports of new insights, a change in perception, e.g. of the urgency, or relevant aspects, of an already ‘symbolic’ role encompasses contributions to putting an issue on the agenda as well as a change in perception, e.g. of the urgency, or relevant aspects, of an already entered point on the agenda. A computer model had a relational role when the data suggested that the model enhanced network building and co-ordination.

4.1. GOAL and the Netherlands Scientific Council for Government Policy

The general optimal allocation of land use (GOAL) linear optimization model (Van Latesteijn, 1995; Rabbinge and van Latesteijn, 1992) links the technical possibilities for land-based agriculture to a diverse range of socio-economic, agricultural productivity and environmental policy goals to calculate a number of land use alternatives for the European Union (EU). Through assigning a different priority to each of the policy goals a certain policy view can be represented, e.g. free market and free trade, or regional development. The technical possibilities for land-based agriculture in the EU were quantified by combining agronomic information on the relation between crop properties and production potentials, information on soil properties and historical observations of the weather. Those quantified technical possibilities were confronted with quantified and prioritized policy goals regarding the performance of the agricultural system.

4.1.1. Impact

GOAL was developed to provide the data for the study “Ground for Choices” (1992) of the Netherlands Scientific Council for Government Policy. This Council advises the government – sometimes at the government’s request, but frequently unasked – on issues facing society which are or could become the subject of government policy. In principle, the Council is free to study any issue the government deals with, or should deal with. Ground for Choices evoked an unusual number of reactions for a Scientific Council study according to an administrative employee of the Scientific Council. The senior scientists of the study were invited hundreds of times to present the modelling results at political, policy and scientific meetings worldwide. The results were debated in the Dutch written press (more than 50 items in the first month after presentation) and on radio. The presentation of the study report was a news item on television. The Netherlands Scientific Council for Government Policy itself and collaborators in the study claimed that the Dutch government and agricultural and nature conservation organizations became convinced of the need for further consideration of the options to integrate environmental, nature and forest objectives with agricultural and nature conservation goals. Furthermore, one of the senior scientists was invited to advise the Ministry of Agriculture, Nature Conservation and Food Quality on strategic policy and vision development.

4.1.2. Building a network and model qualities

How did the output of GOAL become noticed? A Council member initiated the study because “I questioned a number of claims in the debate about the reform of the EU’s Common Agricultural Policy”. The results were presented at a time when the

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Overview of investigated grey literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
<td>Reference</td>
</tr>
<tr>
<td>GOAL and the Netherlands Scientific Council for Government Policy</td>
<td>Overview of the media coverage in the first months after presentation of the research report. Minutes of international meetings of the network of directors rural area where EURURALIS was on the agenda. CD-ROM and booklet on EURURALIS 1.0 EURURALIS Newsletters.</td>
</tr>
<tr>
<td>EURURALIS and the European network of directors of rural area</td>
<td><a href="http://www.tradefolks.montana.edu/ecuador.htm">http://www.tradefolks.montana.edu/ecuador.htm</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Answers to the three research questions (Section 2) per case</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOAL</td>
<td>EURURALIS</td>
</tr>
<tr>
<td>Roles</td>
<td>Heuristic, symbolic</td>
</tr>
<tr>
<td>Building of a network</td>
<td>Initiated and maintained by modellers</td>
</tr>
<tr>
<td>Communication was explicit component of project management</td>
<td>Model development is used as reason for interactions in network</td>
</tr>
<tr>
<td>Privileged position of project leader</td>
<td>Work on TOA was part of larger project, comprizing a range of research and intervention activities</td>
</tr>
<tr>
<td>Contextualization was a major activity in the network</td>
<td>Exploration of management and technical alternatives</td>
</tr>
<tr>
<td>Qualities of model</td>
<td>Encapsulates different views on future developments</td>
</tr>
<tr>
<td>Explores space for manoeuvre</td>
<td></td>
</tr>
</tbody>
</table>

This section consists of three subsections. In each subsection one case analysis is presented. Per case, first a particular land use model is briefly introduced, after which its impact and the three formulated questions (see Section 2.3) are addressed in three paragraphs. The paragraphs on ‘Impact’ and ‘Which roles’ relate to question 1. The paragraphs on ‘Building a network and model qualities’ relate to questions 2 and 3. The main findings are summarized in Table 2.
discussion about the reform of the Common Agricultural Policy was heated. According to the scientists involved, Dutch policy and policy-oriented research institutes, as well as European and foreign national institutes in Europe were purposefully approached for data and feedback on results to foster credibility and visibility from the start of the project. The leaders of the Dutch political parties in the national parliament were each informed about the outcomes of the study before the official presentation; preliminary results were presented at a meeting of the ministers of agriculture of the EU member states in the Netherlands. Also, Dutch nature conservation and agricultural organizations were introduced to the modelling work. According to the member of the Netherlands Scientific Council involved, all those efforts to communicate about the project were facilitated through his contacts and political experience. Amongst others, he was a member of the council of a Dutch agricultural organization that both represented the interests of the sector in politics and had the responsibility to execute agriculture-related public policies (‘Landbouwschap’) and a member of the council of a large national nature conservation organization. Moreover, he had been politically active in different public organs for two decades already.

4.1.3. Which roles?
The above listed impacts of the work with GOAL suggest that GOAL contributed to understanding (heuristic role) and adaptation of the agricultural policy agenda (symbolic role). Respondents and the Netherlands Scientific Council for Government Policy claim that the relations between differing issues proposed in GOAL, such as high-input agriculture and nature conservation convinced the government and societal stakeholder groups of the relevance of a debate about a rural area policy in order to address not only agriculture but also other land uses. Thus, GOAL contributed to the reframing of the issue in terms of a rural, rather than a purely agricultural development question. We hypothesize that GOAL had heuristic and symbolic roles because: (1) the study was published at an appropriate point in time, i.e. the EU agricultural policy reforms were intensively debated at the time outcomes were presented. Because of those debates, people were perceptive to a new contribution; (2) From the start the project team invested in contextualization and communication of their work to the target groups, facilitated by the contacts of the project leader; (3) GOAL related differing issues that were previously debated in isolation. Subsequently, it could suggest new spaces for manoeuvre because of the integration of those differing issues. We did not find any indications that GOAL fostered community development (i.e. a relational role).

4.2. EURURALIS and the European network of directors of rural areas

EURURALIS (Westhoek et al., 2006; Verburg et al., 2006) assesses the effects on landscape of plausible changes at the European level in political and socio-economic conditions. To this end, EURURALIS assesses scenarios of plausible changes as defined by globalization drivers and the control of governments of societal developments. EURURALIS includes a chain of models. A macro-economic model first calculates the economic consequences of a certain scenario for the agricultural system. The output of the macro-economic model is fed into an integrated assessment model to calculate yields, the demand for land, feed efficiency rates and environmental indicators. A subsequent model allocates land to different land uses.

4.2.1. Impact

In 2002, Wageningen UR and the Netherlands Environmental Agency were asked by the Dutch Ministry of Agriculture, Nature and Food Quality to develop an, at least partly quantitative, discussion support tool. In 2007 and 2008, the ministry funded a second and third version of the tool ‘EURURALIS’, respectively. In parallel with the development of EURURALIS the Dutch Ministry of Agriculture, Nature and Food Quality initiated a network of directors of rural areas of agricultural ministries of the European Union (EU) member states. According to a respondent of the ministry, it is likely that this newly established network would cease to exist if the EURURALIS modelling work were no longer part of the network.

4.2.2. Building a network, and model qualities

In the first instance, EURURALIS was not meant to become enrolled in the EU-wide directors’ rural area network. The development of the tool was commissioned in response to an interpretation about the vision of the Minister on the development of the Dutch rural area, according to the respondents of the Ministry and two of the collaborators in the Ground for Choices study (see Section 4.1). The latter had joined the governing bodies. They used the interpretation to initiate a follow-up of the Ground for Choices study. EURURALIS was in the first place intended for a meeting of the Ministers of Agriculture from the EU member states. This initiative did not last. However, “The project was then adopted by the rural area team of the ministry to contribute to a meeting of the directors of ‘rural area’ from the different EU member states. Our director wished to create a European network of national policy makers, similar to the already existing networks around water and nature conservation, to address the future of the rural areas and to develop an EU rural policy agenda” (employee of the Dutch Ministry of Agriculture, Nature and Food Quality). Those existing networks evolved around EU policy instruments, such as the Water Framework and the Habitat directive. A similar tangible occasion was lacking in the case of the rural areas. According to the employee of the Ministry, the team felt that EURURALIS could fill this gap. EURURALIS was installed on laptops for the directors of rural areas of EU member states to explore model output during a 2-day meeting. According to the scientists and employee of the Ministry involved, the rural area directors especially appreciated the possibility of employing the EURURALIS tool as a card index and the visualization of output in land use maps because these features helped the users to get an overview of the diversity in developments and interdependencies in the rural area at both national and European level. The Dutch rural area team asked for a second version of the model. The progress of EURURALIS 2.0 was regularly discussed with the Dutch policy makers, in an international policy advisory board and in subsequent meetings of the EU rural area network. Even when the second version was not yet delivered, the rural area team of the Dutch Ministry of Agriculture, Nature Conservation and Food Quality had already commissioned a third version. Moreover, a representative of the Ministry together with the project co-ordinator visited network participants in the different countries to discuss EURURALIS on a bilateral basis.

4.2.3. Which roles?

With the second version still to be presented and a third version commissioned, it is likely that the roles of EURURALIS will be negotiated in the future. At the moment, respondents explicitly refer to its community-creating role, i.e. without the model, the rural area directors network would fall apart. Furthermore, its heuristic role was acknowledged, i.e. EURURALIS helped the users to develop an idea of relevant aspects and interdependencies at both national and European levels. The Dutch rural area team foresees a symbolic (putting issues on the agenda) role for EURURALIS. Their purpose with investing in the network is to develop a widely approved agenda on EU rural area policy. To this end, the second and third version of EURURALIS will allow the user to implement policy instruments under all four scenarios to assess
their impact. The analysis presented above suggests that EURURALIS has heuristic and relational roles because: (1) EURURALIS provides flexibility in the sense that it offers four elaborations (i.e. four scenarios) of the same question ("What are plausible changes in land use?") and can therefore accommodate diverse perceptions. This flexibility suits the explorative stage the network is presently at. The actors in the network do not need to agree on what exactly entails rural area development to communicate about model outcomes; (2) The rural area team of the Dutch Ministry of Agriculture, Nature Conservation and Food Quality employed presentations of output of EURURALIS to structure network meetings, and will use EURURALIS as an occasion to visit European colleagues. The team has purposefully enrolled EURURALIS as a means to establish a network and initiate a discussion on rural area policy at the European level.

4.3. TOA and potato production in Ecuador

The Trade-off Analysis Model (TOA, Stoorvogel et al., 2004; Crissman et al., 1998) is a modelling framework for integrating disciplinary data and models for trade-off analysis. TOA was developed to examine pesticide impacts on agricultural production, human health, and the environment in the highly commercial potato growing province of Carchi, Ecuador. For a trade-off analysis, an inventory is made of possible sustainability indicators of a particular system, whereafter a selection is made. Hypotheses are formulated regarding the relationships between these indicators, so called 'trade-off curves', and policy or technology interventions that might shift the curves. The subsequent analysis to quantify the trade-off curves uses spatially explicit econometric simulation models linked to spatially referred bio-physical simulation models.

4.3.1. Impact

The policy debate on pesticides in Ecuador in the 1980s was largely driven by environmental groups claiming that pesticides were having significant environmental impacts. Scientists who worked on the impacts of pesticide use in Ecuador, claim that the output of TOA contributed to the shift in attention from environmental towards human health impacts of pesticide use. As a result, a committee composed of directors from the National Agricultural Research Institute, the Ministry of Education, and the Ministry of Health drafted a 'declaration for life, environment and production in Carchi' to call for action at the provincial level in 1999. In 2001, a similar call was made by a committee of national stakeholders. According to the scientists involved, video and other visual images of the fluorescent tracers of pesticides on individuals' body surfaces as well as in their homes, were particularly useful in creating a sense of urgency. Subsequently, TOA created a basis for discussing alternatives, e.g. TOA outcomes suggested that both integrated pest management and applicator safety measures improved economic returns as well as health outcomes.

4.3.2. Building a network and model qualities

How did TOA become enrolled in this power play? An international group of researchers developed TOA to explore the trade-offs between economic, environmental and health indicators in Carchi, Ecuador. To develop specific components of TOA, the researchers worked with stakeholders in the study area. Stakeholder meetings were held to identify key sustainability indicators and their trade-offs, and relevant policy and technology scenarios. A 2-year survey was conducted for 187 fields of 40 farmers, with approximately monthly visits to each farmer to obtain data about management practices on each field they managed. According to one of the international researchers, the extensive contacts of the International Potato Research Institute (CIP) and the national agricultural research institute in the area facilitated these research activities considerably. The modelling work took place in the context of a larger research–intervention project that included amongst others health studies of the neurological impacts of pesticide exposure on farmers and their families, sociological studies of farmers’ practices related to pesticide use and educational programmes. In the framework of this larger research–intervention project, a few times per year local and provincial stakeholders and the researchers were convened to discuss research results. One of the major province-wide stakeholder meetings attracted 105 representatives from the government, industry, development organizations, communities and the media.

4.3.3. Which roles?

The work on TOA was part of a larger research–intervention project. Moreover, it integrated data and insights from other activities within the framework of this larger project. Nevertheless, it appeared possible to analyse TOA’s (partial) contributions and induce its roles from this analysis. The analysis presented above suggests that TOA improved understanding (heuristic role) and fostered network building (relational role). Moreover, similar to GOAL (Section 4.1) TOA influenced the framing of the problem of intensive pesticide application practices in Carchi that had already entered the agenda (symbolic function). To start with the heuristic and symbolic roles, the integrative capacity of TOA was complementary to video and other visual research methods; the empirical work had an awareness-raising effect while the modelling work demonstrated until then unknown relations between health and productivity and herewith created space for alternatives. With reference to the relational role of TOA, a respondent from an NGO working on empowerment in Carchi noted: “For me, the data collection and modelling activities were most useful when they involved diverse stakeholders early on in the process, and as such contributed to new relationships and changing perceptions and senses of responsibilities. At the end of the day, the relationships and emergent networks of actors seem to make greater contributions than the raw data and its extrapolations.” Why did TOA have these roles? Although it is particularly hard in this case to unravel the relationships and interactions because of the manifold related and in parallel occurring research and intervention activities, our hypothesis is that it was the regular interactions between all involved actors due to model contextualization activities and meetings organized in the framework of the research–intervention project, in combination with the necessary involvement of a diverse range of stakeholders to provide input for model development.

5. Discussion and conclusions

Land use modelling addresses issues related to agricultural policy making, land use planning and integrated water management, in this paper referred to as complex problems because those issues often concern multiple stakeholders with divergent objectives, and perspectives. Computer models were found to perform heuristic (improving understanding), symbolic (putting the issue on the political agenda) and relational (creating a community) roles in complex problem solving (Shackley, 1997). The conceptual framework presented in Section 2 suggests that a land use model can only perform a role in problem solving when it is enrolled in the interactions by one or more of the stakeholders. It then gets a different status because it becomes part of the interactions, is contextualized and its role is being defined. From the conceptual framework, three questions were derived to further investigate in three case studies how models get roles in complex problem contexts. Those questions were: (1) What role(s) did the model play in the course of the interactions? (2) How did the model become part of the interactions in the network? (3) Which model qualities
contributed to the actual role(s) of the model? In this section, these three questions are addressed from an integrative perspective.

Concerning the first question, what stands out is that all three models studied had a heuristic role and that it was characteristic system research features, i.e. the study of interactions between components, and the integrative capacity, that were mentioned as important characteristics in relation to this role (question 3). Though in all three cases the computer model had a heuristic role, it always came in combination with at least one other role. This other role(s) was more directly connected with the social ambitions that were present in a specific case study. In two cases (GOAL and TOA), the land use model had a symbolic role. Also in two cases (TOA and EURURALIS), modelling work fostered network building around the land use issue at stake (relational role). This is a role of land use models that has rarely been highlighted in the literature to date. However, we deem it a highly relevant subject for further research. Network building around a land use problem is one aspect of the pressing issues of linking social and ecological systems and building the capacities of communities to manage natural resources in a sustainable way (see e.g. Fabricius et al., 2007; Reynolds et al., 2007).

Concerning questions 2 and 3, a comparative analysis of the three case studies (Table 1) suggests that the particular qualities of the land use models (i.e. the characteristic system research features as discussed above) as well as network building and contextualization contributed to the acceptance of the land use models in a network. Contextualization was defined (Section 2.2) as the combination of explication of values and aspirations, fitting to context and interpretation of model work in relation to other knowledge sources. The case studies presented show that the land use models were not accepted in a network by chance. In all three cases, substantial investments were made in enrolling and contextualizing the land use model concerned and maintaining relations with relevant stakeholders. It was not one particular actor (group) that made these investments. In the TOA and GOAL cases, it was scientists who took the initiative to enrol a model in the network. In the EURURALIS, the user was the instigator. Thus, considering the presented conceptual elaborations and the empirical observations it is plausible that both network building and contextualization are relevant for effective model use in a multi-stakeholder context. Strikingly, other features typically associated with the use of land use models, such as the representation of uncertainties in computer models, the ease of use of graphical user interfaces, and transparency (e.g. Mysiak et al., 2005; Oxley et al., 2004; Saloranta et al., 2003) were hardly mentioned spontaneously as relevant model qualities in this respect. This suggests that these latter qualities are not key to the heuristic capacity of land use models. Although such qualities may make it easier to learn from models, the real stimulants to learning seem to be more related to getting an integrated understanding of substantive relationships. Data of three partial cases is far too limited to draw any generic conclusions. However, these case study observations are in line with our other investigations of model use (Sterk et al., 2006, 2007).

This paper set out to investigate how models get to perform certain roles in a complex problem solving context. The developed conceptual framework (Section 2) drew the attention to the importance of contextualization of a model and the social interactions surrounding land use model development and application. The analysis of the three case studies (Section 3) suggests that network building and contextualization are indeed explanatory factors, as well as characteristic system modelling qualities, i.e. the study of interactions between components, and an integrative capacity. Furthermore, the data analysis revealed that in complex societal problem solving, land use models perform heuristic roles in combination with at least one other role. In view of the presented innovative findings, we consider the proposed perspective of roles of land use models that emerge through interactions in networks is helpful to the understanding of model utilization in multi-stakeholder contexts.

Acknowledgements

The authors acknowledge the contributions of Huib Hengsdijk, Jetse Stoorvogel, Willem Rienks, Stephen G. Sherwood and the other individuals who gave generously of their time.

References


